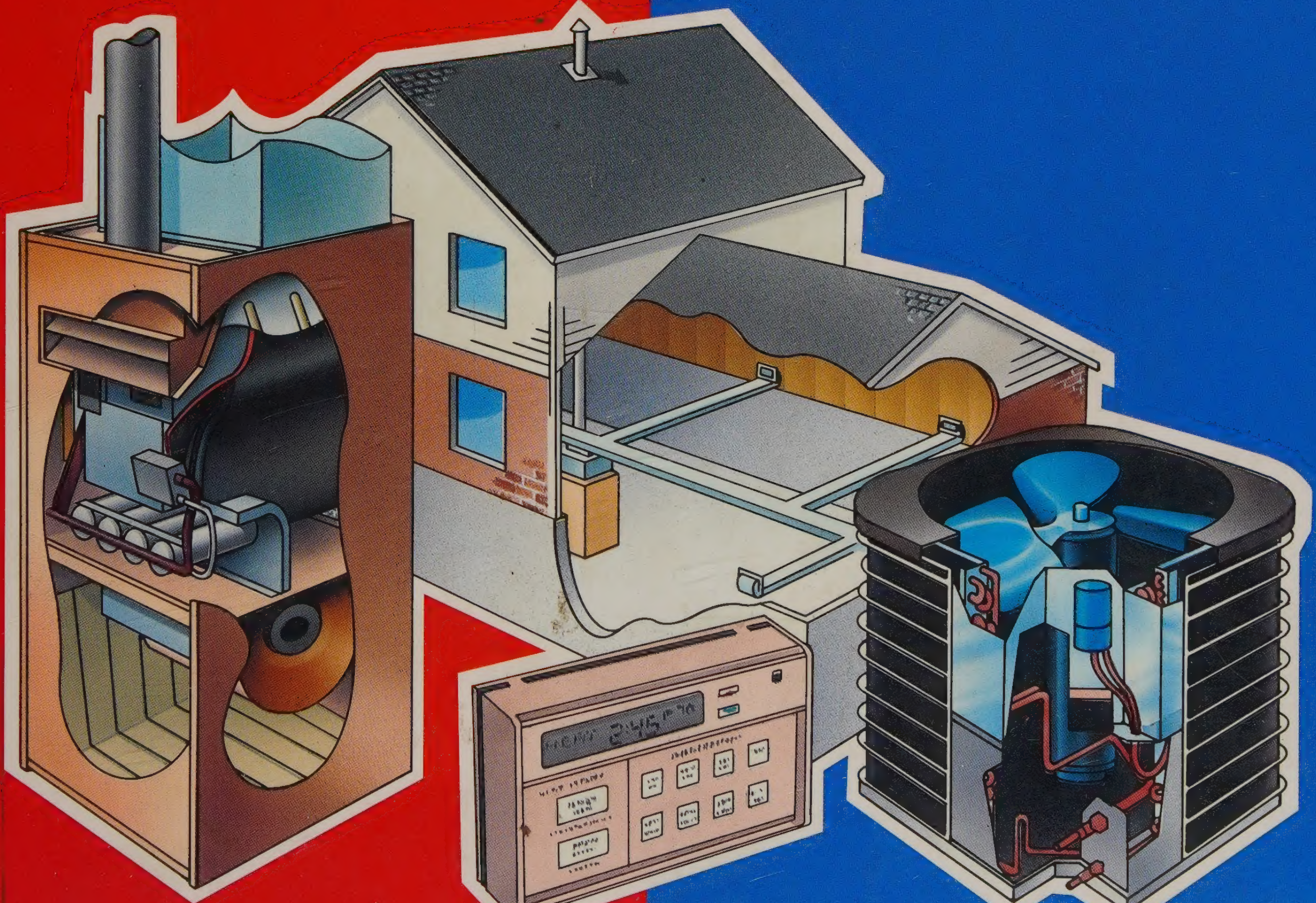
Heating and Cooling Essentials

Jerry Killinger
LaDonna Killinger



Heating and Cooling Essentials

by
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ABOUT THE AUTHOR

Jerry Killinger has extensive experience in both teaching and in the hands-on installation and servicing of air conditioning, refrigeration, and heating systems. He has worked with industrial, commercial, and residential systems ranging from heat pumps to boilers to cooling towers to refrigerated food cases to solid state environmental control equipment. Jerry has taught for more than 15 years in both traditional vocational class settings and in various seminar and workshop situations. He currently conducts intensive seminars on refrigeration, air conditioning, and electricity for industrial maintenance personnel at facilities of major manufacturers across the United States.

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INTRODUCTION

Heating and Cooling Essentials was written to provide a thorough, easily understood, and up-to-date textbook for persons entering the refrigeration, air conditioning, and heating field. The text combines a practical blend of theory with on-the-job skill-building procedures.

Heating and Cooling Essentials is designed for use by first-year students in HVAC programs at vocational schools, technical schools, or community colleges. It also may be used in apprenticeship programs or adult-education classes, and can serve as an excellent self-study text for technicians already working in the field.

The book provides a solid foundation in the basics, and uses practical service procedures to implement the technical theory. It gives students a thorough and accurate guide to troubleshooting and to performing essential service procedures on many types of systems. It is a valuable source of the latest technical information on new refrigerants designed to avoid further depletion of the ozone layer, new oils for use with non-CFC refrigerants, and the recovery and recycling equipment now in use. The required changes in service procedures to avoid release of refrigerant into the atmosphere are clearly explained.

Heating and Cooling Essentials is organized into areas of study based on a progression of concepts and systems from the simple to the more complex. Each chapter also develops topics progressively, allowing you to build upon existing knowledge. Learning objectives are provided at the beginning of each chapter to serve as an overview of content, and a summary and review questions are provided at the end. The questions give you an easy means of assessing whether the chapter material has been mastered, or whether additional study is needed before moving on.

Numerous original illustrations are included in **Heating and Cooling Essentials** to help you understand the materials being presented. The drawings are designed to aid in relating the information presented to the actual components and equipment that will be encountered in the field.

This textbook should provide you with a sound and solid foundation for further study of more specialized aspects of the HVAC field.

Jerry Killinger
LaDonna Killinger

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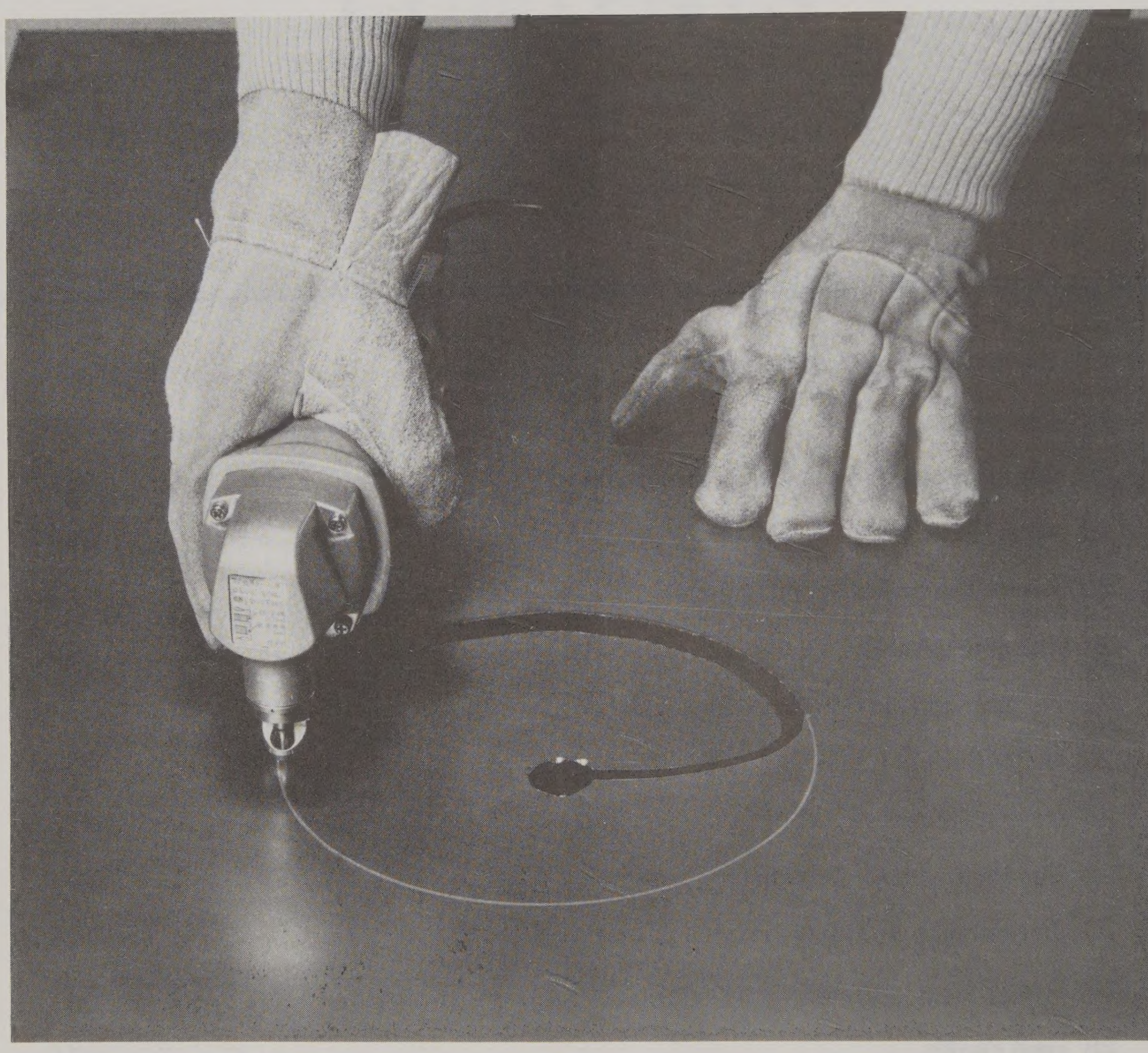


While the HVAC technician most often uses hand tools, specialized power tools like this sheetmetal nibbler save time and effort in certain situations. (Makita)

Chapter 1
HAND TOOLS

After studying this chapter, you will be able to:
- *Identify the various types of hand tools.*
- *Describe the advantages and disadvantages of each type of hand tool.*
- *Select the proper hand tool for the job.*
- *Demonstrate skills in using various hand tools.*
- *Maintain, repair, or replace damaged tools.*
- *Demonstrate good craftsmanship in the performance of daily tasks.*

NEW WORDS

arbor	serrated
cheater	shank
cheek	socket
flutes	swing space
hex-head	torque
hexagonal	universal joint
mushroomed	whetstone
points	

TOOLS FOR TECHNICIANS

The job of the refrigeration, heating, and air conditioning technician consists mainly of performing mechanical operations, and using common tools and materials. A good technician performs each task properly *the first time,* and does it *right*. Tool skills are acquired through experience and practice. Such skills are very valuable to the technician.

Successful technicians select quality tools, care for them properly, and *are skilled in their use*. Technicians who have good tool skills also have good mechanical skills. Misuse of tools indicates poor mechanical skills that can result in delays, callbacks, and injuries.

A beginning technician usually starts with a basic set of hand tools for regular use, and then gradually adds other tools as needed. Some technicians carry often-used hand tools in a tool pouch; others prefer toolboxes.

Master technicians may have several boxes of tools, so that they can use *exactly the right tool for the job*.

WRENCHES

Wrenches are the most widely used type of hand tool. They are used to hold or turn nuts, bolts, cap screws, and other fasteners, and also can be used to clamp parts together. Applying too much ***torque*** (turning force) can strip bolt threads, or break off bolt heads. Good wrenches are designed to keep leverage and load in safe balance. *Never* use a pipe extension or other form of ***"cheater"*** to increase leverage of any wrench.

Always select a wrench with an opening that exactly fits the nut. **Wrench size** is determined by measuring across the jaw opening. The wrench size is stamped on the side of the tool.

OPEN-END WRENCHES

Open-end wrenches have an open jaw on each end, Fig. 1-1. Each end is a different size and the jaw opening is set at an angle. The angle permits using the wrench when there is only a small amount of room (***swing space***) to turn the nut or bolt. The wrench is turned over to obtain a new grip on the nut. Because they tend to slip, open-end wrenches are best for use on *loose* nuts and bolts. A slipping open-end wrench can result in hand injuries and in rounding of the nut edges.

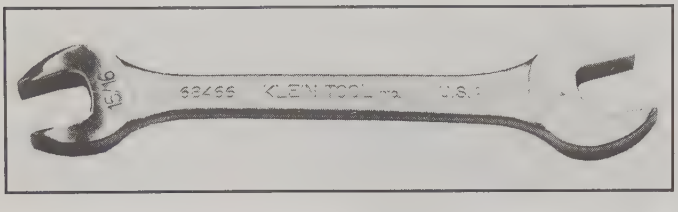


Fig. 1-1. The openings are a different size at each end of an open-end wrench . (Klein Tools, Inc.)

BOX-END WRENCHES

Box-end wrenches are closed on both ends, to surround the nut or bolt head. See Fig. 1-2. Each end has an opening of a different size. Opening sizes are stamped on the wrench. Box wrenches are available in 6-point or 12-point types. ***Points*** are the "teeth" that grip the edges of the nut or the bolt head. The 6-point wrench is the stronger of the two, since it has more grip area. A box-end wrench will not slip easily, so it should be used on tight or partially rounded bolt heads or nuts.

COMBINATION WRENCHES

Combination wrenches combine the best features of open-end and box-end wrenches. They have one open end and one box end, Fig. 1-3. Both ends are usually the same size. The combination wrench is designed for several tasks. The open end is useful where little swing space is available. The box end provides necessary grip area for final tightening (or loosening of tight bolts).

VALVE KEY WRENCHES

Valve key wrenches or **refrigeration wrenches** are designed for easy turning of valve stems. See Fig. 1-4. This wrench is a ratchet type with square openings to fit most valve stems. A quick-flip reversing lever permits instant reversal for turning service valve stems in either direction. This wrench is a *must* in every technician's tool kit.

FLARE-NUT WRENCHES

The **flare-nut wrench**, shown in Fig. 1-5, is a special type of box wrench with an *opening* in the box. The opening permits the wrench to be slipped over tubing and onto the flare nut. Each end of the flare-nut wrench has a different-size opening.

ADJUSTABLE WRENCHES

Adjustable wrenches have a movable lower jaw, Fig. 1-6. Like open-end wrenches, these wrenches tend to slip. If you use an adjustable wrench, make sure it is *tightly* adjusted to the nut. Pull only in the direction that will put force on the side of the *fixed* jaw. See Fig. 1-7.

ALLEN WRENCHES

An **Allen wrench,** also known as a **hex wrench,** is a hardened steel shaft with a special ***hexagonal*** (six-sided) shape. It is used most often to turn set screws that anchor

Fig. 1-2. Box-end wrenches completely surround the nut or bolt head. This racheting model can be used in tight spaces where swing room is limited (Vaco Products)

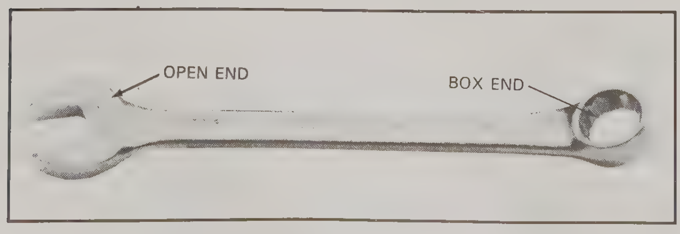


Fig. 1-3. The open end and box end of a combination wrench are usually the same size. (Klein Tools, Inc.)

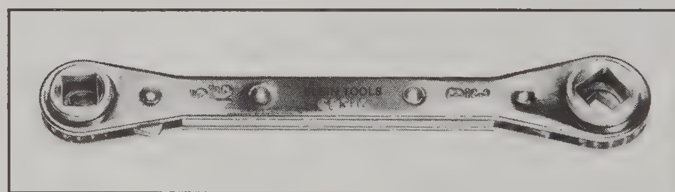


Fig. 1-4. The ratchet feature of the valve key wrench makes it easy to turn a valve stem, even in tight quarters. This wrench is a necessity for every technician. (Klein Tools,Inc.).

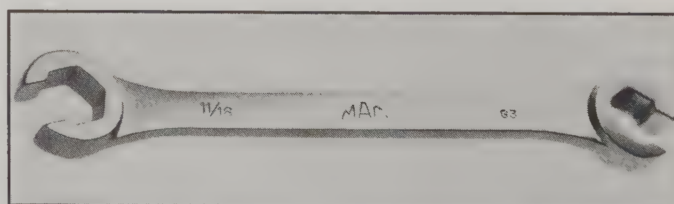


Fig. 1-5. The opening in the box of the flare-nut wrench allows it to slip over tubing and fit a flare nut tightly. (Mac Tools, Inc.)

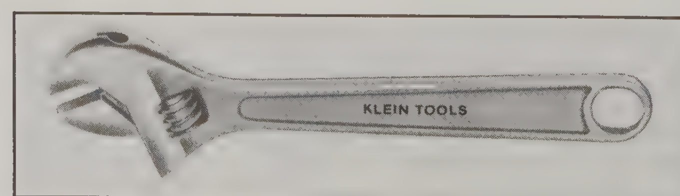


Fig. 1-6. An adjustable wrench tends to slip, unless the movable jaw is tightened firmly on the nut or bolt head. (Klein Tools, Inc.)

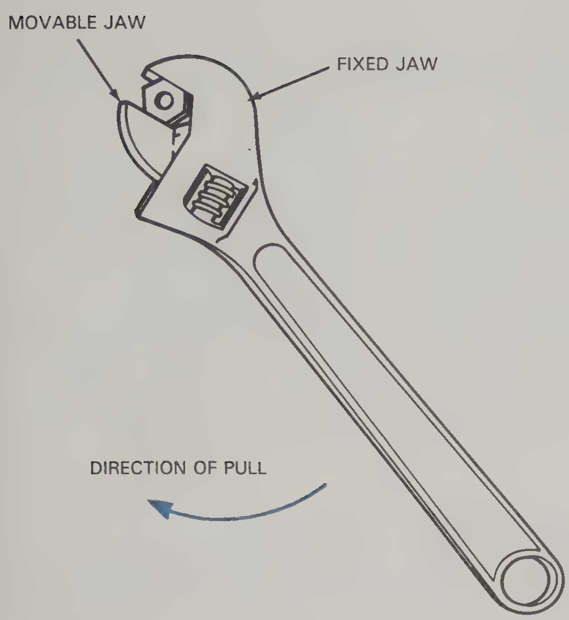


Fig. 1-7. When using an adjustable wrench, pull only in the direction shown, so that force is exerted on the fixed jaw.

pulleys or fan blades to a shaft. Allen wrench sets are available in "jackknife" style, or as long individual wrenches, Fig. 1-8. Long wrenches allow easy access to set screws used to anchor fan blades and pulleys to a shaft. To prevent damage to the wrench, be sure that it is fully inserted in the screw before turning.

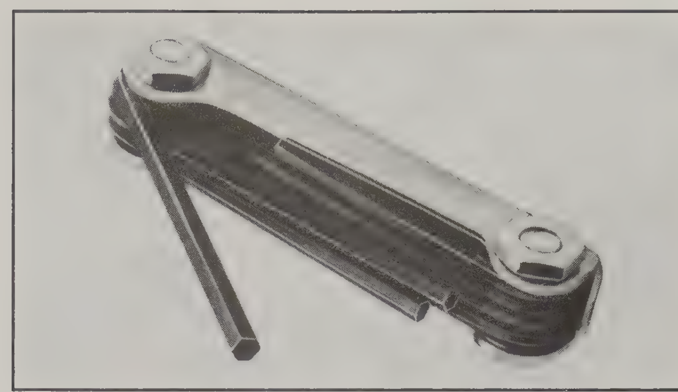
SOCKET WRENCHES

A ***socket*** is an individual cylinder-shaped box-end tool, used with a handle to perform the same turning tasks as other wrenches. One end of the socket fits over the bolt head or nut. The other end has a square opening for attaching the drive. Sockets are available in multiple sizes, and are often sold in sets like the one shown in Fig. 1-9.

Drive sizes and socket points. As shown in Fig. 1-10, the square drive opening of a socket may be 1/4 in., 3/8 in., 1/2 in., or 3/4 in. The drive size is a measure of the socket's capacity to withstand torque (turning force). Small drives are used for small fasteners; large drives for large fasteners.

Socket nut openings may be square (4-point), 6-point, 8-point, or 12-point. The square and 8-point sockets are used on nuts and bolts that have square heads. The 6-point sockets have more grip area than 12-point sockets; both are used on fasteners with hex (six-sided) heads. However, 12-point sockets can be used with either square-head or ***hex-head*** bolts. Sockets of the 6-point type are most popular.

Socket handles. Various kinds of socket handles are made to fit into the square drive opening of the socket. **A ratchet**, Fig. 1-11, is the most commonly used socket handle. Ratchets have a quick-flip reversing lever for instant reversing of socket rotation. Using excessive force can damage the ratchet mechanism.



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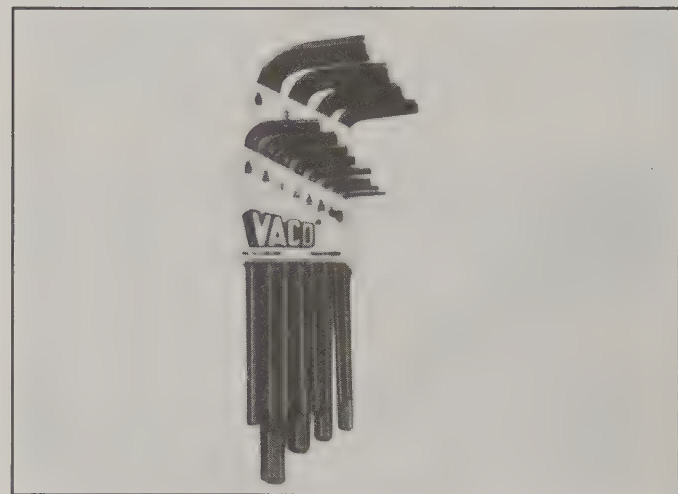


B

Fig. 1-8. Allen wrenches, or hex wrenches, fit hexagonal recesses in set screws and other fasteners. A–Jackknife style set. (Vaco Products) B–Individual wrenches. (Vaco Products)

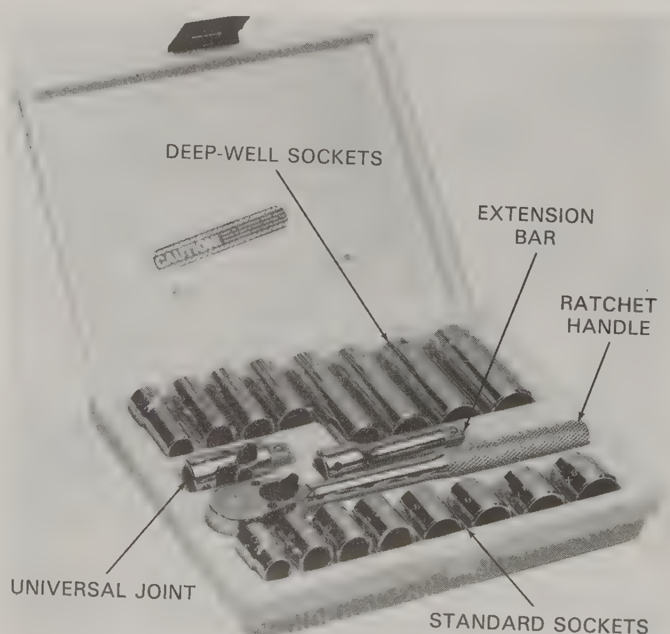


Fig. 1-9. Socket wrench set with both standard-length and deep-well sockets. (Mac Tools, Inc.)

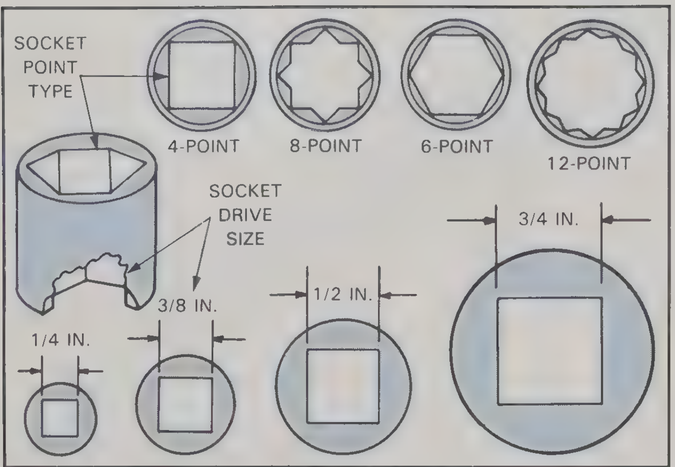
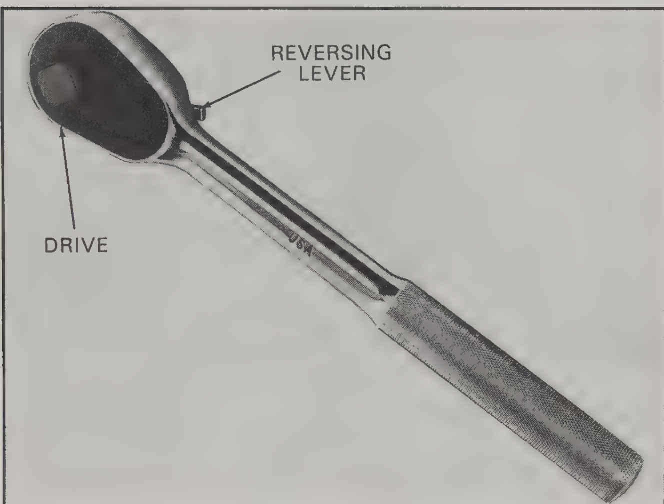


Fig. 1-10. Sockets are available in several different drive sizes and in different point configurations.



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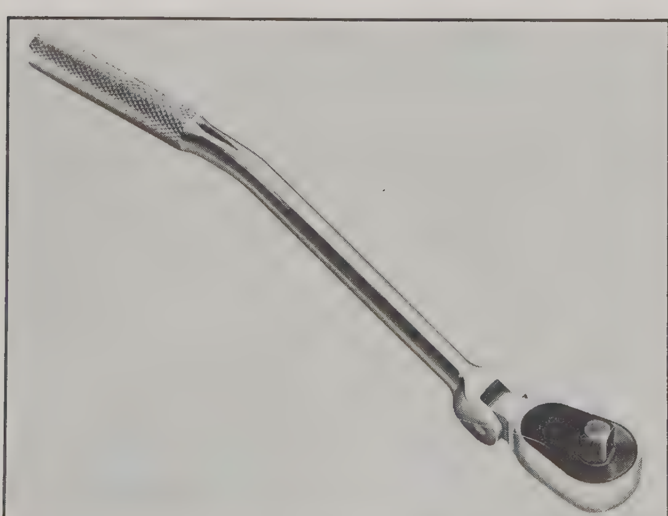

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Fig. 1-11. Ratchet handles allow tightening or loosening fasteners when only limited swing space is available. The reversing lever allows easy change of direction. A–Standard ratchet handle (Mac Tools, Inc.) B–Offset ratchet handle. (Mac Tools, Inc.)

A **breaker bar** is the strongest socket handle. It is used when breaking loose extremely tight nuts and bolts. After the bolt or nut is loosened, the ratchet handle is used to finish removing the fastener.

Extension bars, Fig. 1-12, are used to provide added reach between the socket and its handle. Extension bars are available in different lengths and can be combined for added reach. Extension bars permit reaching fasteners that are surrounded by other parts.

A ***universal joint*** is a type of swivel that permits reaching around objects. It is used between the socket and drive handle, and can be used with an extension bar. Do not use the universal joint at too sharp an angle. This places excessive stress on the swivel. See Fig. 1-9.

USING WRENCHES SAFELY

- Never use a wrench to do the job of another tool.
- Never use a wrench opening that is too large for the fastener.
- Never push a wrench beyond its capacity. Quality wrenches are designed and sized to keep leverage and intended load (torque) in safe balance. The safest wrench is a box or socket type, because it is less likely to slip off the bolt head.
- Never expose a wrench to excessive heat.
- Never *push* on a wrench unless absolutely necessary. You should always *pull* on a wrench to protect your knuckles. If you must push, use the open palm of your hand, with fingers slightly curled.
- Never cock or tilt an open-end wrench.
- Never depend on plastic-dipped handles for protection against electrical shock. These handles provide comfort and a firmer grip, **not** shock protection.

REPAIR OR REPLACE?

Worn out or broken tools are not safe or efficient. They can be dangerous to the user and those working nearby. Repair or replace worn tools as required. The cost of a new tool is small when compared to the cost of an injury or of time that is wasted by substandard performance.

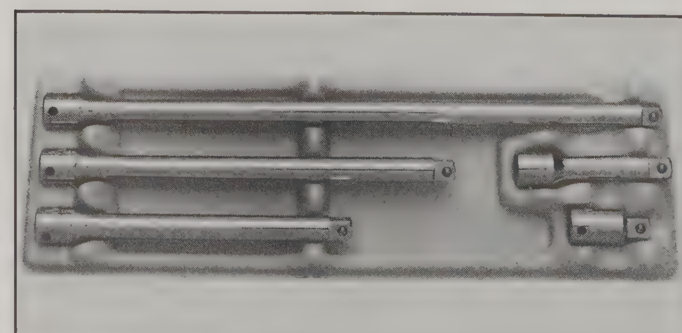


Fig. 1-12. Extension bars are used, singly or in combination, to allow tightening or removing fasteners that otherwise could not be reached. (Mac Tools, Inc.)

Repairing box, open-end, or combination wrenches is *not recommended.* Such wrenches should be discarded and replaced if they have bent handles, rounded or damaged box points, or jaws that are spread, nicked, or battered.

Ratchets and adjustable wrenches often can be repaired by replacing the damaged parts. However, an adjustable wrench with a bent handle or a fixed jaw that is spread or damaged should be discarded and replaced. Bent socket wrench handles and extensions, and cracked or battered sockets, also should be discarded and replaced.

PLIERS

Pliers are used to grip, cut, crimp, hold, or bend various materials. Each type does its particular job better than another type. Choosing the correct type of pliers improves efficiency.

LINEMAN'S PLIERS

Lineman's pliers, also called **side-cutting** pliers, are a heavy duty tool available in various sizes, Fig. 1-13. These pliers have a strong side-cutting feature for cutting larger-size wires. This tool should be in every technician's tool kit.

LONG-NOSE PLIERS

Long-nose pliers, Fig. 1-14, are available in three nose designs; needle, round, and flat (sometimes called "duck bill"). They allow the technician to reach into awkward places and perform work difficult to do with any other tool. They are available with or without side cutters. Most long-nose pliers are designed for electrical use, but are useful in other ways if they are not abused. To avoid damage, never *pry* with these pliers, or try to bend *stiff wire* with the plier tips. Also, avoid exposing these pliers to excessive heat: the jaw tips will bend outward and render them useless. The long-nose pliers recommended for refrigeration, heating, and air conditioning work are the heavy duty 8 in. (203 mm) size, with cutter, in the round pattern.

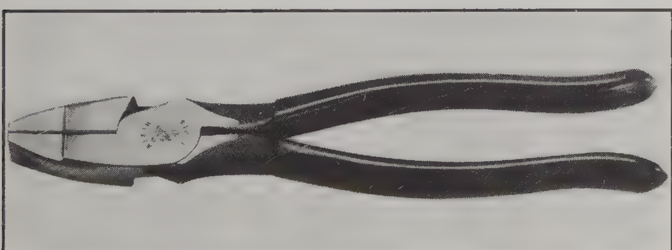


Fig. 1-13. The lineman's, or side-cutting, pliers is a basic item of the technician's toolbox. Plastic covered handles, like those shown on these pliers, provide a better grip on the tool. They do *not* protect against electrical shock. (Klein Tools, Inc.)

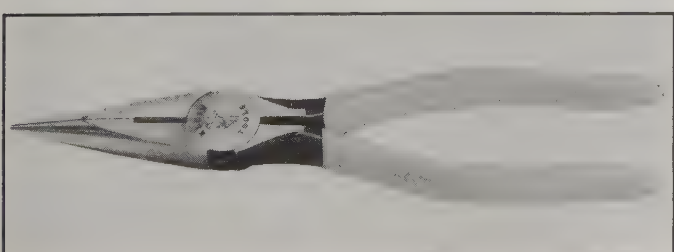


Fig. 1-14. Long-nose pliers are available in needle-, round-, and flat-nose types. (Klein Tools, Inc.)

DIAGONAL CUTTING PLIERS

Diagonal cutters (often called "dikes") are designed for cutting electrical wires, cotter pins, nails, and other types of fasteners. See Fig. 1-15. When cutting wire *always* cut at a right angle to avoid damage to the pliers, and *do not* rock them from side to side. The 8 in. (203 mm), heavy duty type is best for refrigeration, heating, and air conditioning work.

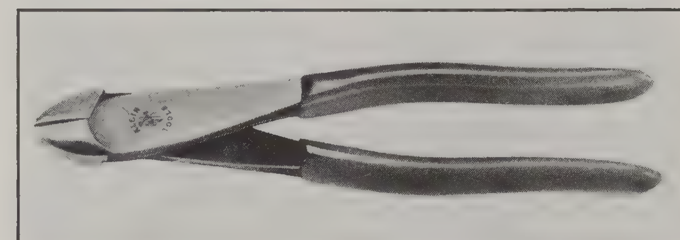


Fig. 1-15. Diagonal cutting pliers are used for heavier cutting tasks than other types of pliers. (Klein Tools, Inc.)

PUMP PLIERS

Pump pliers, also known as utility or **groove-joint** pliers, are used by all types of mechanics. See Fig. 1-16. The jaws are positioned and locked into place by engaging the tongue in the proper groove. A series of grooves gives a range of jaw openings to as much as 4 inches (102 mm), and will not slip even under heavy pressure. They will grip round, square, flat, and hexagonal objects. Pump pliers can apply limited torque without damage to the work.

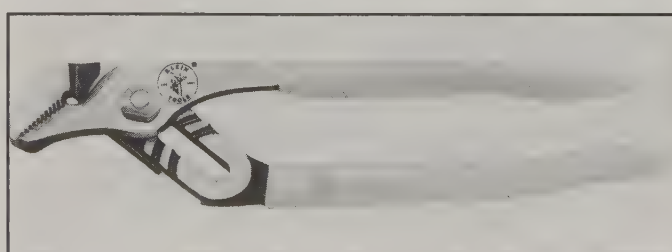


Fig. 1-16. Pump pliers provide a strong, non-slip grip on either round or square objects. (Klein Tools, Inc.)

SLIP-JOINT PLIERS

Slip-joint pliers, Fig. 1-17, are an older but still widely used style. The slip joint provides two jaw positions, and the pliers may have a shear-type wire cutter. These pliers are designed for a wide range of service involving gripping, turning, and bending.

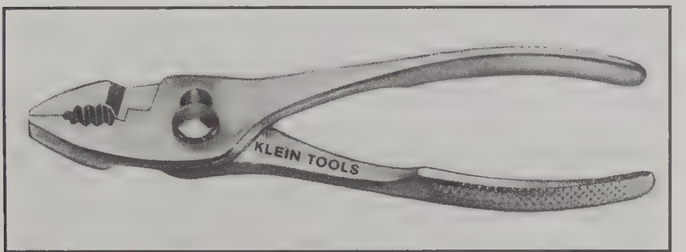


Fig. 1-17. Slip-joint pliers are an ''all-purpose'' tool for gripping and holding objects. (Klein Tools, Inc.)

LOCKING PLIERS

Locking pliers are available with straight or curved jaws, in a variety of sizes, Fig. 1-18. These pliers use a compound leverage system to lock the jaws for holding various shapes and sizes of work. This is a combination tool that functions as pliers, wrench, portable vise, or clamp. Because of their clamping power, locking pliers can free both hands for doing other work (such as brazing, sawing, or drilling). Locking pliers can sometimes be used to unscrew fasteners that have stripped or rounded heads. Since they will mar surfaces, however, never use locking pliers on good nuts and bolts. Attempts to repair this tool are not recommended.

USING PLIERS SAFELY

- Never use pliers to do the job of another tool.
- Never push pliers beyond their capacity. Bending stiff wire with light pliers or the tip of needle-nose pliers can spring or break the tool.

Fig. 1-18. Locking pliers are versatile, and can be used to hold objects and free both hands for other tasks. They are available with straight or curved jaws. (Klein Tools, Inc.)

- Never expose pliers to excessive heat. Direct flame on metal can draw the temper and ruin the tool. Cutting pliers are especially vulnerable to high heat.
- Never cut hardened wire with ordinary pliers. Also, never rock pliers from side to side when cutting wire, or bend the wire back and forth against the cutting knives. These practices can dull or nick cutting edges.
- Never cut any wire or metal unless your eyes and your fellow workers' eyes are protected. *Safety goggles are an absolute must.*
- Never depend on plastic-dipped handles to insulate you from electricity. They are intended for comfort and improved grip, not protection against electric shock.

REPAIR OR REPLACE?

While repairing pliers is not recommended, regular maintenance is a *must*. Dull cutting knives may be sharpened, and the hinge should receive an occasional drop of oil. Pliers that are cracked, broken, sprung, or have nicked cutting knives should be discarded and replaced.

SCREWDRIVERS

Screwdrivers are used to drive or withdraw such threaded fasteners such as wood screws, machine screws, and self-tapping screws. Screwdrivers are available in a wide variety of shapes and sizes, Fig. 1-19. The right tool is vital for fast, efficient driving and removal

Fig. 1-19. Screwdrivers are available in a wide variety of sizes, shank lengths, and tip shapes. (Vaco Products)

of screws. Screwdriver tips are designed to tolerate a limited amount of strain or torque. A screwdriver that is too long or too short, or does not fit the screw properly, Fig. 1-20, can waste time and cause damage to the fastener.

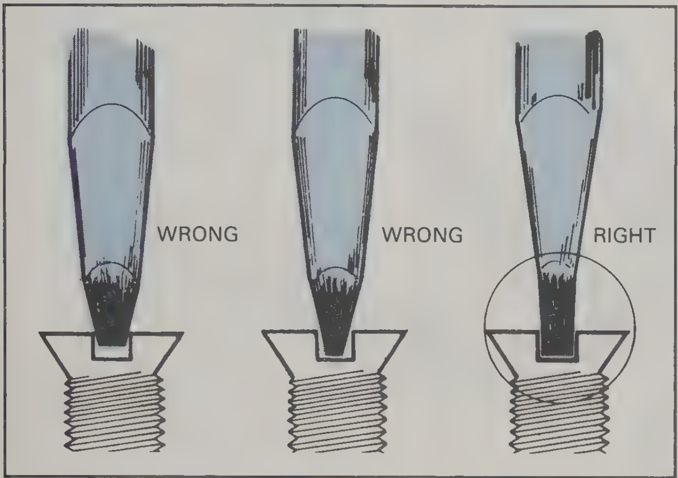


Fig. 1-20. The tip of the screwdriver must fit the slot properly to avoid the danger of damage to the slot or slipping and possible injury. (State of Ohio)

SPECIAL SCREWDRIVERS

Reversible screwdrivers have a different tip at each end of the ***shank*** (shaft). The driver handle is removable and fits either end of the shank. See Fig. 1-21. Reversible drivers are available with different combinations of driver tips. The most common is one with a standard tip at one end and a Phillips tip at the other.

The **screw-holding screwdriver** is a must for working in close quarters or electrical boxes. Screw-holding drivers are used only to get the screw firmly started. After starting, a conventional driver is used for further driving. Fig. 1-22 shows the two types: one that holds by means of pressure against the sides of the screw slot, and one that has spring-steel fingers to grip the screw head.

Screwdrivers for **Torx®, Allen, Posidriv®**, and other special screwhead patterns are available in many sizes and lengths. Fig. 1-23 shows these special patterns.

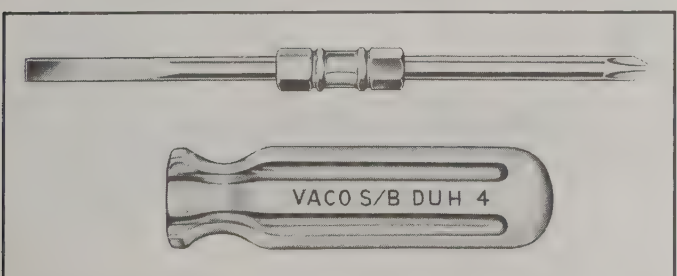
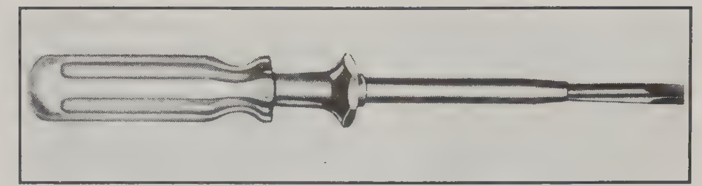


Fig. 1-21. Reversible screwdrivers usually have a Phillips tip at one end and a standard (straight-blade) tip at the other. (Vaco Products)



A

B

Fig. 1-22. Screw-holding screwdrivers. A–Type with split tip that exerts pressure on the sides of the screw slot. (Vaco Products) B–Type with spring-steel fingers that grip the head of the screw. (Vaco Products)

Fig. 1-23. In addition to standard and Phillips screwhead patterns, there are a number of special patterns like those shown here. The Torx® pattern is widely used in the automotive industry, for example. (Vaco Products)

NUT DRIVERS

Nut drivers are special tools with a 6-point socket at the tip of a screwdriver-type handle, Fig. 1-24. Nut drivers are useful for removing and replacing small hex head (six-sided) screws and nuts. Nut drivers are available in sizes ranging from 3/16 in. to 5/8 in. Handles are usually color-coded for quick selection of size. Hollow shaft nut drivers are considered best for general use.

USING SCREWDRIVERS SAFELY

- Always fit the tool to the work. The size of the screw and the type of drive opening determines which driver to use.

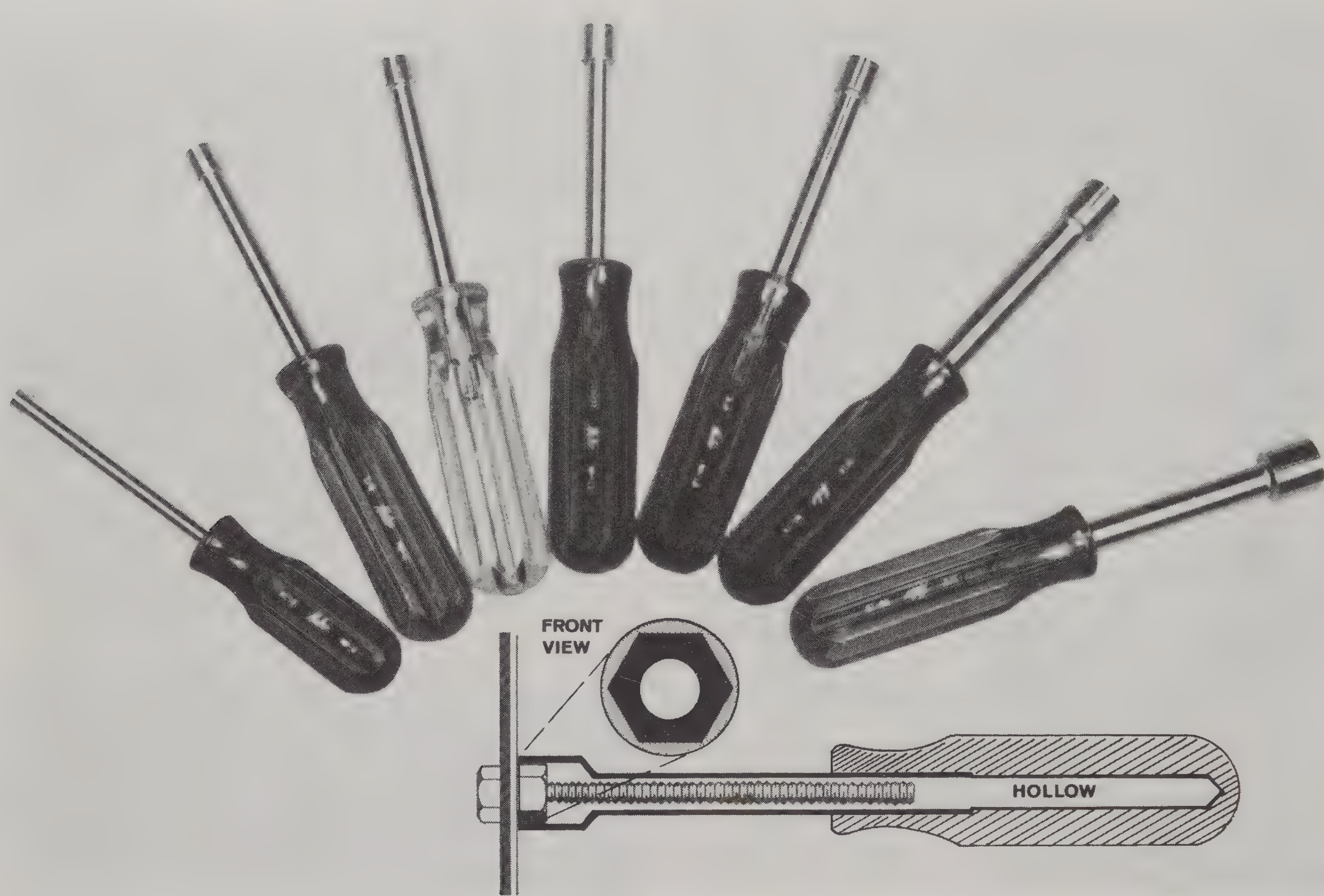


Fig. 1-24. Nut drivers like these hollow-shaft types usually have handles that are color-coded for easy identification. (Malco Products, Inc.)

- Never use a driver to do the job of another tool.
- Never push a driver beyond its capacity. For heavy work requiring the use of a wrench to help do the turning, use a square-shank driver.
- Never use a driver at an angle to the screw. This could allow the driver to slip, possibly damaging the screwhead or causing an injury.
- Never expose a driver to excessive heat.
- Never depend on a driver's handle or covered blade to insulate you from electricity.

REPAIR OR REPLACE?

Do *not* attempt to repair most types of drivers. Drivers with cracked handles, bent or twisted shafts, or worn tips should be discarded and replaced. The tip of straight-blade (slotted-screw) drivers, however, can be dressed on a bench grinder. Be careful to avoid letting the tip get hot. This will draw the temper (hardness), so the tip becomes soft and easily damaged.

HAMMERS

Hammers are used for striking operations of various types. It is important to use the right hammer and use it properly. For example, you should not use a nail hammer to strike a chisel or other hardened tool. Don't use a soft-faced hammer to drive a nail, or a sledge-type hammer for a brad.

NAIL HAMMERS

Nail hammers are made in two patterns, curved claw and straight claw. See Fig. 1-25. They are available in

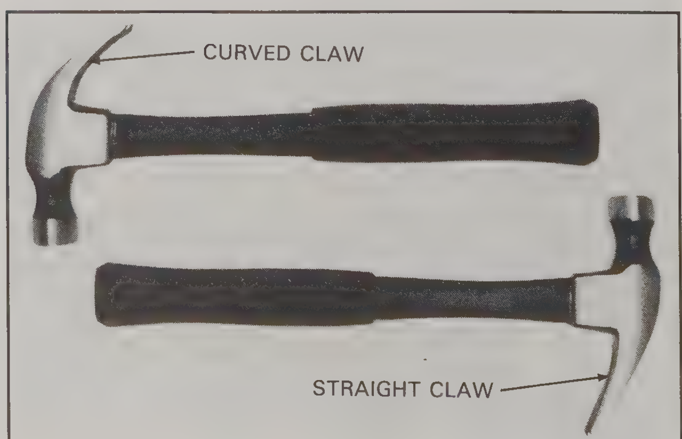


Fig. 1-25. Nail hammers are available in a variety of weights, and in either curved-claw or straight-claw types. (Malco Products, Inc.)

various head weights for different types of nailing: 16 oz. (450 g) and 20 oz. (570 g) hammers are for general use; 22 oz. (625 g) and 28 oz. (795 g) hammers are used for heavy duty framing work. Framing hammers usually have longer handles than those for general use. Handles are made of wood, fiberglass, or steel. Never drive hardened-steel cut nails or masonry nails with a nail hammer. These nails will shatter under the force of an indirect or glancing blow. Instead, use an engineer's (sledge-type) hammer.

BALL PEIN HAMMERS

Ball pein hammers, Fig. 1-26, are one of the most-used hammers. Ball pein hammers are designed for striking chisels and punches, and for riveting, shaping, and straightening metal. They are available with head weights of from 2 oz. to 48 oz. (55 g to 1360 g) for different tasks. When striking a tool like a chisel or punch, the hammer face should be 3/8 in. (9.5 mm) larger than the struck tool.

SOFT-FACED HAMMERS

The heads of **soft-faced hammers** or mallets are made of wood, rawhide, rubber, plastic, copper, or brass. See Fig. 1-27. They are used where steel hammers would mar or damage the workpiece. Never use a soft-faced hammer to strike sharp metal objects or to drive nails or screws.

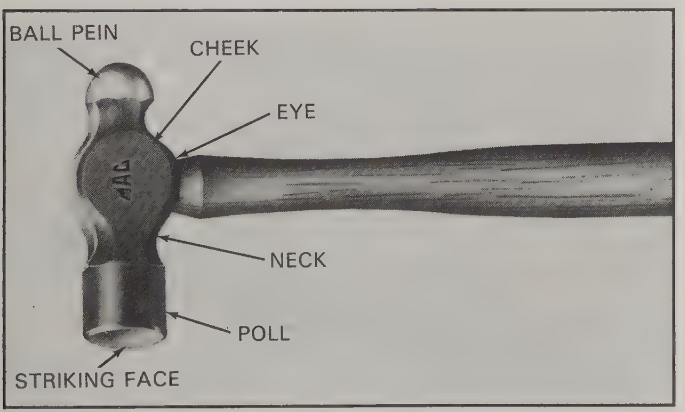


Fig. 1-26. The ball pein hammer is the proper tool to use when striking cold chisels or punches. (Mac Tools, Inc.)

ENGINEER'S HAMMER

Engineer's hammer or **sledge-type hammer**, Fig. 1-28, is designed for heavy duty striking work. Weights are typically 2 1/2 lb. to 4 lb. (1.1 kg to 1.8 kg). This type of hammer is commonly used for striking spikes, cold chisels, and hardened nails.

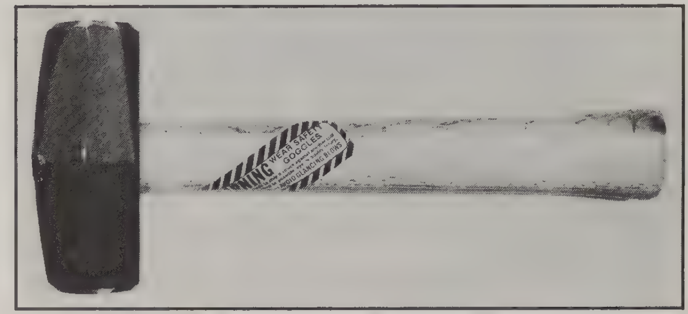


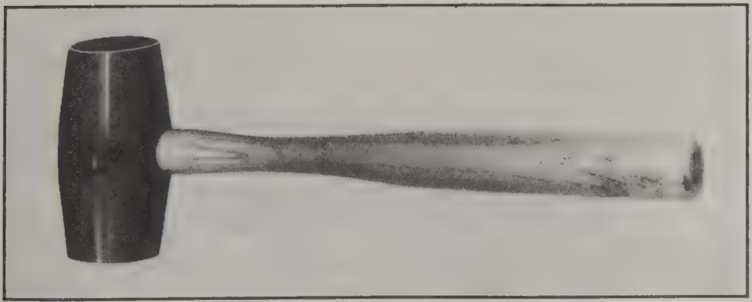
Fig. 1-28. The engineer's hammer, or sledge, is used for such tasks as driving hardened nails. (Mac Tools, Inc.)

SETTING HAMMERS

Setting hammers are designed for work on sheet metal. See Fig. 1-29. They have square, sharp corners and straight sides to form sharp corners and to close seams. The corners and sides of the setting hammer are easily chipped if incorrectly used.

USING HAMMERS SAFELY

- Always align the face of the hammer squarely with the surface being struck. Avoid glancing blows.
- Never use a nail hammer to strike a chisel or other hardened objects, such as masonry nails. The hammer face may chip and cause injury.
- Always wear safety goggles when using a hammer to drive nails or strike objects.



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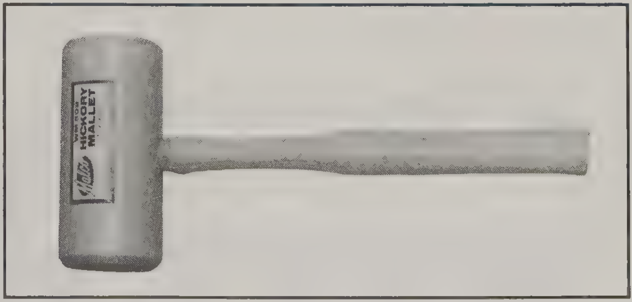


B

Fig. 1-27. The heads of soft-faced hammers or mallets are made from such materials as rawhide, rubber, wood, or plastic. Some types have replaceable plastic tips. A–Rubber mallet. B–Wooden mallet.(Malco Products, Inc.)

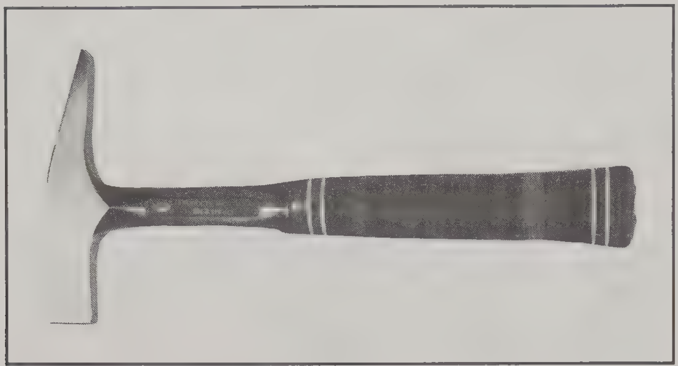


Fig. 1-29. Setting hammers have square heads that make them ideal for forming seams and corners in sheet metal. (Malco Products, Inc.)

- Never strike one hammer with another hammer.
- Never use a hammer that has a loose or damaged handle.
- Never use the side or *"cheek"* of a hammer for striking any object.
- Never grind or redress the face of a hammer. If the hammer head is damaged, discard and replace it.

REPAIR OR REPLACE?

Discard hammers that have damaged heads; they are dangerous to use. Damage is indicated by dents, chips, excessive wear, or broken claw. Damaged wood or fiberglass handles can usually be replaced.

HACKSAWS

Hacksaws are used to cut all types of metal objects. See Fig. 1-30. Hacksaw blades are selected according to the number of teeth per inch: 18 (coarse), 24 (medium), and 32 (fine). The blade should be fastened tightly in the frame, with the blade teeth pointed *away* from the handle. At least two teeth should contact the metal being cut, or the saw will catch and bind.

You can use one or two hands on the saw to make cuts. Press down lightly on the forward stroke and release pressure on the backstroke. Avoid rapid strokes, or blade will overheat and become dull. Use 50 to 60 strokes per minute.

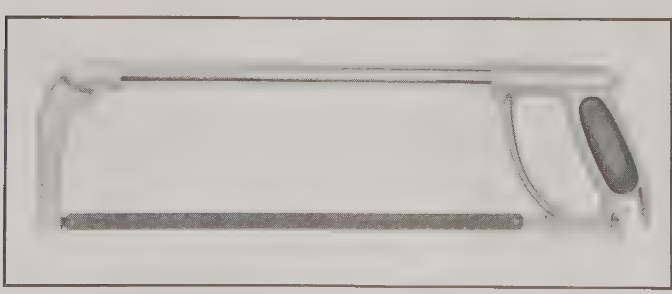


Fig. 1-30. The hacksaw is an important tool for cutting metal. Blade teeth should face away from the handle, so that the saw cuts on the forward stroke. (Malco Products, Inc.)

Small (sometimes called "mini") hacksaws, Fig. 1-31, are used for working in very confined areas, or for flush cutting. These small hacksaws are indispensable to the technician.

DRILL BITS

Various types of drill bits are used for cutting holes. Each is designed for use on a specific type of material: drill bits designed for wood cannot be used on metal or concrete; bits for metal can be used on wood, but not concrete; bits for concrete cannot be used on metal or wood.

TWIST DRILL BITS

Twist drills bits are used to cut small-diameter holes in metal or wood. Bits made of high-speed steel are most common, and are sometimes carbide-tipped. A twist drill bit has three principal parts: a *shank* that is clamped into the drill chuck, a *body* with two spiral grooves called ***flutes,*** and a cone-shaped cutting end called the *point*. See Fig. 1-32. The flutes act as channels for the escape of metal chips from the hole being drilled. Twist drills can be purchased separately or in sets, with drill sizes ranging from 1/16 in. to 1/2 in. See Fig. 1-33.

WOOD BITS

The **spade-type wood bit** is designed to cut straight or angled holes in wood, plastic laminate, plaster, foam insulation, and similar materials. Like twist drills, they

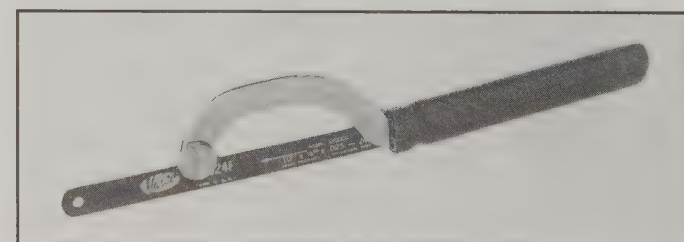


Fig. 1-31. For flush-cutting metal or for work in close quarters, the mini-hacksaw is the ideal tool. (Malco Products, Inc.)

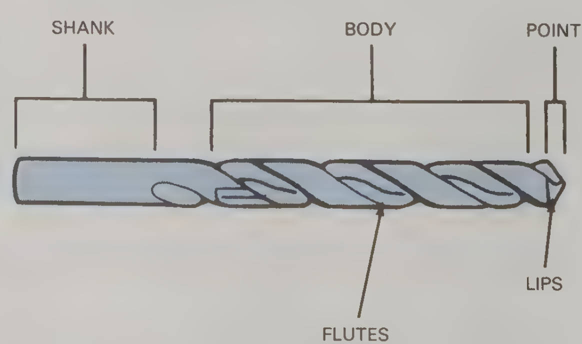


Fig. 1-32. Parts of a typical twist drill bit.

Fig. 1-33. Twist drill bits are available individually or in sets. Most often, a technician starts with a set, then replaces bits individually as necessary. (Malco Products, Inc.)

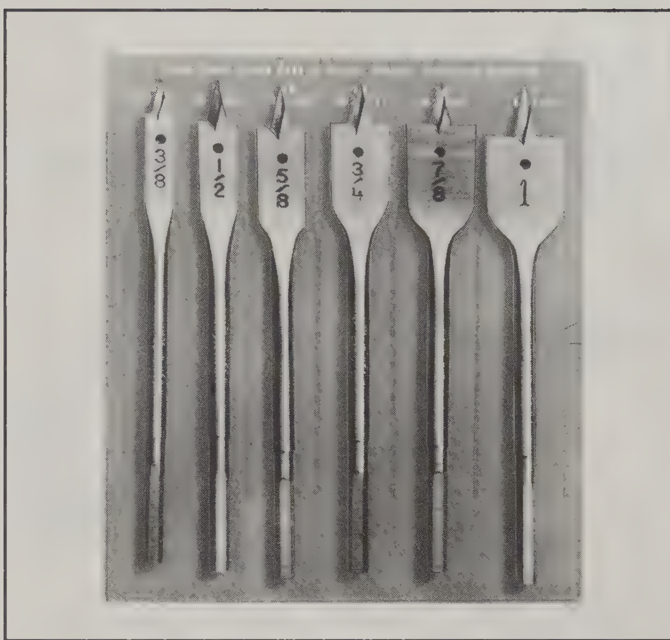


Fig. 1-34. Spade-type bits are used to bore medium-to-large-size holes in wood and similar nonmetal materials. Sizes are stamped on each bit. (Milwaukee Electric Tool Corp.)

are available as individual bits or in sets, in sizes ranging from 1/4 in. to 1 1/2 in. (6 mm to 38 mm). As shown in Fig. 1-34, sizes are stamped on each bit. Spade-type bits can be resharpened with a file or grinder. Extension bars are available for extended reach.

Auger-type wood bits are generally used for drilling larger holes, and are available in sizes up to 2 1/2 in. (63.5 mm). The pilot screw tip draws the bit into the wood. Cutting blades can be sharpened with a file. See Fig. 1-35.

HOLE SAWS

High-speed **hole saws** are designed for cutting steel, aluminum, copper, brass, sheet metal, stainless steel, wood, or plastics. See Fig. 1-36. The high-speed cutting edges are welded to steel bodies to produce clean, accurate holes. Shatter-resistant construction makes them safe and durable. Hole saw sets, Fig. 1-37, are available that include sizes ranging from 9/16 in. (14 mm) to as much as 5 in.(127 mm). Individual hole saws are quickly attached to an ***arbor*** (spindle or axle) that has a twist drill for starting the pilot hole.

MASONRY BITS

Masonry bits, Fig. 1-38, are used for drilling brick, stone, concrete, and ceramic materials. Such holes are often needed to allow use of concrete anchors or similar fasteners. The special carbide tip resists dulling. Flutes remove dust from the hole, so that the bit cuts at maximum efficiency without clogging. Bits may be resharpened on a bench grinder, using a silicon carbide grinding wheel. Sizes range from 1/8 in. to 1 1/2 in. (3 mm to 38 mm)

Star drills are designed for hand-drilling of holes in masonry. See Fig. 1-39. The bit is held in place with one hand, while being struck with an engineer's hammer held in the other hand. The bit must be rotated slightly after each blow. The four cutting edges steadily chip into the material with each blow. Always wear safety goggles when using any form of masonry bit. *Never* use

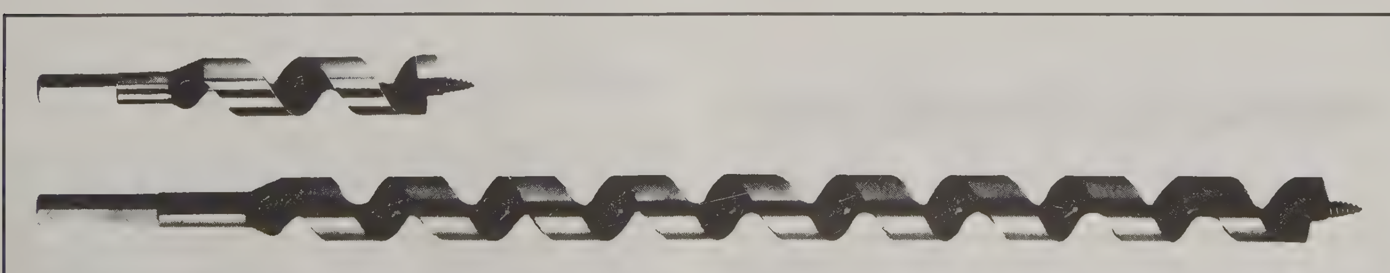


Fig. 1-35. Auger-type bits have a pilot screw to draw the bit into the wood or similar material being bored. There are several types of auger bits. A ship auger is illustrated. (Klein Tools, Inc.)

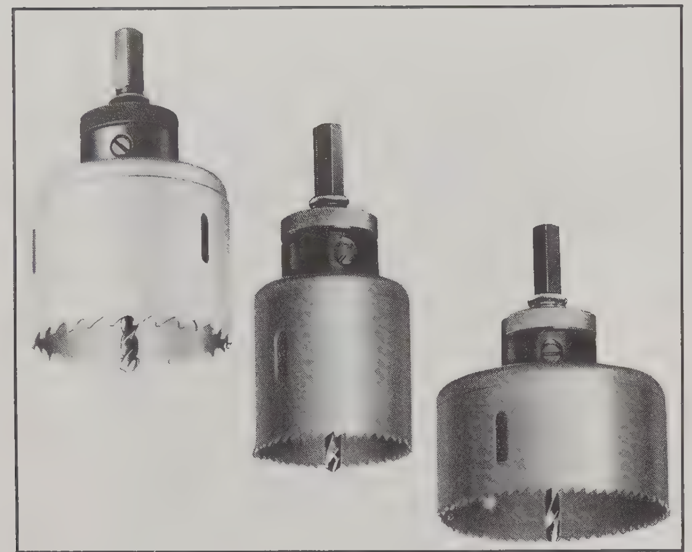


Fig. 1-36. Hole saws are attached to an arbor that includes a twist drill bit that bores a pilot hole. The saw at left is a carbide-tipped deep-cutting type. A deep-cutting saw without carbide tips is at center, and a standard-depth saw at right. (Milwaukee Electric Tool Corp.)

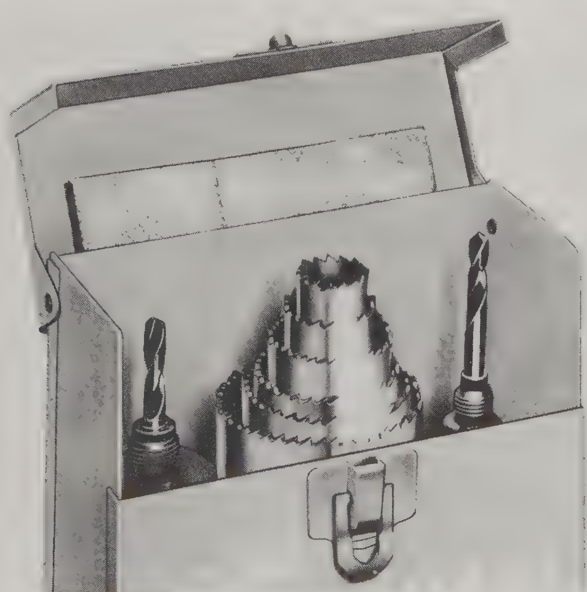


Fig. 1-37. Hole-saw sets include one or more arbors and a range of saw sizes for holes of different diameters. (Milwaukee Electric Tool Corp.)

Fig. 1-38. A carbide-tipped masonry drill makes fast work of holes in concrete, brick, and similar materials. Note the reduced shank that allows use of the drill in a chuck with an opening smaller than the drill size. (Milwaukee Electric Tool Corp.)

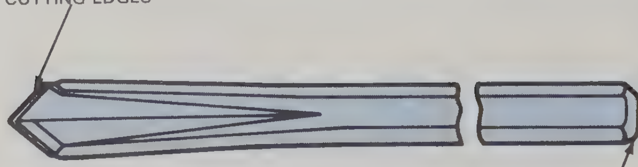


Fig. 1-39. The star drill is struck with a sledge-type hammer to make holes in concrete or masonry materials. (Star Expansion Co.)

a star drill with a struck face that is chipped or ***mushroomed*** (flattened and spread out from being struck).

SNIPS

Snips are used to cut sheet metal, screens, gaskets, and straps. There are four basic types in common use: straight-pattern, combination, duckbill, and aviation. Snips are made for right-handed use, although they can be used in either hand.

There are other types of snips available, such as the *curved blade, bulldog, double-cut,* and *jeweler's.* These types of snips are used by professional metalworkers or a special profession.

STRAIGHT SNIPS

Straight-pattern snips, Fig. 1-40, are generally used for making straight-line cuts. Curved cuts can be made if the curve is not extreme. Sizes vary from 7 in. to 16 in. (178 mm to 406 mm) overall length. The most popular size is 10 in. (254 mm).

Fig. 1-40. Straight-pattern snips are used primarily for straight cuts, but can make gentle curves, if necessary. (Malco Products, Inc.)

COMBINATION AND DUCKBILL SNIPS

Combination snips, Fig. 1-41, and **duckbill snips**, Fig. 1-42, can be used for straight cutting as well as cutting curves in either direction. When used for straight cutting, both types tend to bend the metal, so they require more effort than a straight-pattern snip. The duckbill snip will cut smooth curves in sheet metal in either direction, Fig. 1-43.

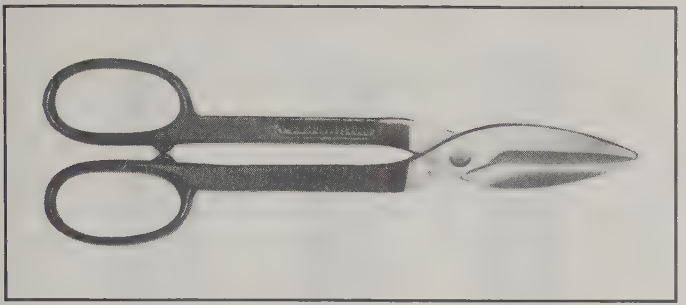
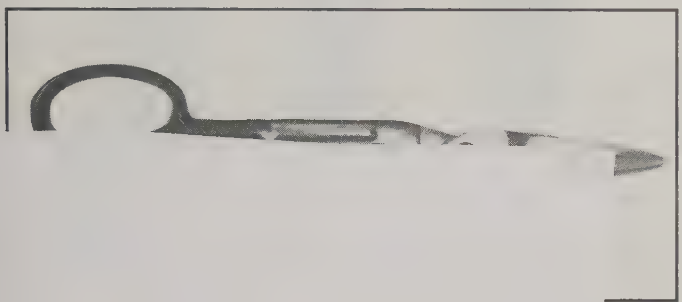


Fig. 1-41. Combination snips can be used for straight or curved cuts. (Malco Products, Inc.)



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AVIATION SNIPS

Aviation snips, Fig. 1-44, are popular in all fields of metalwork. Their compound lever action requires less effort to cut metal than other types of snips. The blades are made of alloy steel, so they are also harder and tougher than regular snips. Standard size for the professional aviation snip is 10 in. (254 mm).

Aviation snips are available in three types of cut, Fig. 1-45. The straight pattern is for cutting straight lines. The left-hand pattern is for cutting curves to the left. The right-hand pattern is for cutting curves to the right. The cutting blades are ***serrated*** (toothed or ridged) to prevent metal from slipping out when pressure is applied to them.

Fig. 1-44. The serrated jaws of aviation snips keep metal from slipping, while lever action makes cutting easier. (Vaco Products)

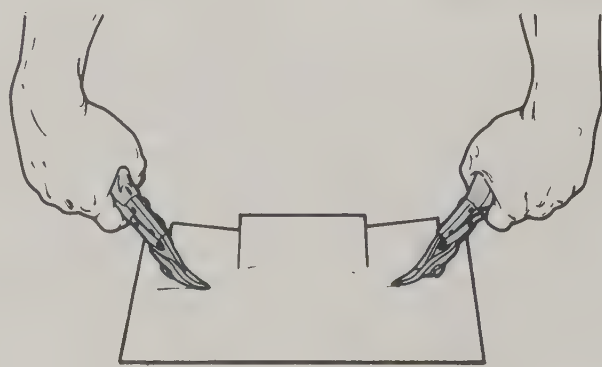


Fig. 1-45. Aviation snips are available in models that are designed for straight cuts, left-hand curves, or right-hand curves. (Vaco Products)

USING SNIPS SAFELY

- Always wear safety goggles when using snips.
- Be careful of sharp cutting edges of the snip blades.
- Always wear gloves to protect against cuts from sharp metal edges.
- Use snips only for cutting soft metal or other soft materials.
- Use only hand pressure for cutting. Never hammer on the snip or use your foot to put extra pressure on cutting edge.
- Perform periodic maintenance to keep snips efficient and safe. Occasionally oil the pivot bolt, and protect the cutting edges from damage. Sharpen the edges as necessary.
- Never try to sharpen an aviation snip. This removes serrations used to grip the metal so that it doesn't slip.

PUNCHES AND COLD CHISELS

Punches and **cold chisels**, Fig. 1-46, are struck tools. They are made of special alloy steel that is heat-treated and drawn to provide maximum resistance to impact. They are designed to direct the force of each blow toward the center, or body, of the tool. Strike the tool squarely – blows that are off-center can damage the chisel or material, and may cause injury. Always use eye protection when using chisels or punches.

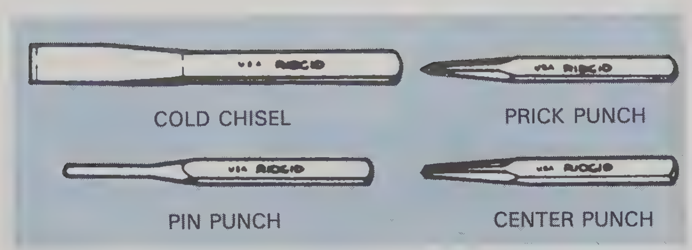


Fig. 1-46. Punches and cold chisels are usually struck with a ball pein hammer. The square shanks of the tools shown make them easier to grip and also prevent them from rolling off the work area. (The Ridge Tool Co.)

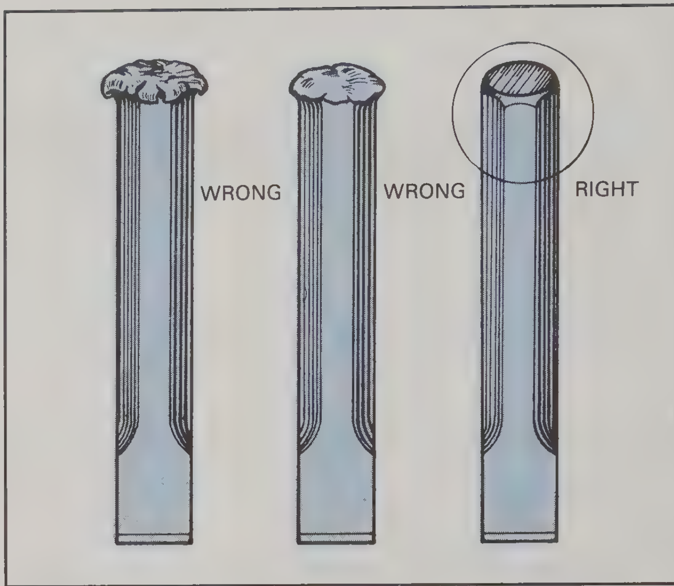


Fig. 1-48. A chisel or punch with a mushroomed head is dangerous, since bits of metal can fly off when the tool is struck. A properly dressed chisel or punch is ground to a smooth chamfer as shown at right. (State of Ohio)

COLD CHISELS

Cold chisels are used to cut off damaged or badly rusted nuts, bolts, rivet heads, or other fasteners, Fig. 1-47. The angle and thickness of the cutting edge is designed to give maximum cut and durability. Never use a chisel that has a mushroomed head (striking face). Use a grinder to *dress* the chisel (remove the mushroomed metal and form a smooth chamfer), Fig. 1-48. A *dull* cold chisel can slip and cause injury. Sharpen the hardened cutting edge as needed with a hand file or a ***whetstone*** (special sharpening stone).

PUNCHES

A **center punch** and the **prick punch** are similar, but the prick punch has a sharper point. Either can be used to mark parts prior to disassembly. This assures proper alignment when the parts are reassembled. A punch is also used to make an indentation in metal before drilling a hole. The indentation prevents the drill bit from wandering (moving).

A **pin punch** has a straight shank for driving pins and rivets out of a hole. They are often used for aligning holes in different sections of material. Never use a punch with a dull, chipped, or deformed point. Such a damaged punch can slip and cause injury.

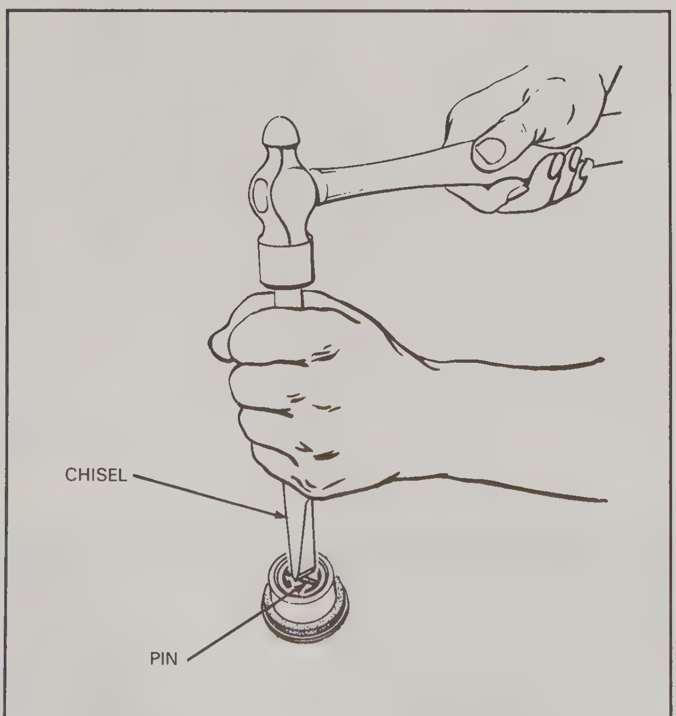


Fig. 1-47. A cold chisel can be used to cut through bolts, pins, or other metal fasteners or parts.

USING COLD CHISELS AND PUNCHES SAFELY

- Always wear eye protection when working with chisels and punches.
- Always strike a punch or chisel squarely. An off-center blow can cause damage or injury.
- Never use a cold chisel to cut or split materials such as stone or concrete.
- Never use a dull chisel or a punch that has a chipped or deformed point.
- Never use a chisel or punch with a mushroomed head. Grind off the mushroom to form a chamfer. Avoid overheating when grinding.

SUMMARY

This chapter has described the most common hand tools used by technicians, how to select them, and how to use them safely. It is almost impossible to perform even the simplest repair without using some type of tool. The *right* tool, used properly, will give satisfactory results. The *wrong* tool, or an *improperly used* tool, gives unsatisfactory results and may cause injury. To select the right hand tool for the job, you must know the advantages and disadvantages of each type.

Selecting the proper hand tool to fit the job is important. A good technician will know when, where, and why a specific tool will work better than another. For example, several different tools (pliers, socket wrench, adjustable wrench, box wrench) can be used to loosen a nut or bolt, but one will do the job best and most safely. Take time to select or obtain the **right** tool. Other tools are introduced and explained in later chapters, as needed. For example, tools used for working with copper tubing are explained in the section devoted to that material.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Misuse of tools indicates poor ________ skills.
2. Name six types of wrenches.
3. The types of wrenches that tend to slip are ________ and ________.
4. What is the safest type of wrench to use on a stubborn nut or bolt? Why?
5. The ________ socket is the most common.
6. True or false? You should always pull on a wrench, rather than push.
7. Plastic-dipped handles *do not* protect against ________ ________.
8. List six types of pliers.
9. Safety goggles are absolutely necessary when using pliers to cut ________ or ________.
10. Name two types of special screwhead patterns.
11. Which hammer is best to use for striking chisels?
12. Hacksaws cut on the ________ stroke.
13. True or false? Twist drills can be used only on wood.
14. Which of these basic types of snips has serrated blades?
    a. Straight-pattern.
    b. Combination.
    c. Duckbill.
    d. Aviation.
15. Since they are used with a hammer, punches and cold chisels are called "________ ________."

The ability to read and interpret such instruments as this multimeter are among the mathematical skills needed by today's technician working in the HVAC field. (Simpson)

Chapter 2

MATHEMATICS FOR TECHNICIANS

After studying this chapter you will be able to:

- *Interpret dimensional information.*
- *Apply math formulas.*
- *Read a ruler properly.*
- *Identify and properly install 45° and 90° elbows.*
- *Record time sheet information accurately.*
- *Convert temperature readings from Fahrenheit to Celsius and vice-versa.*
- *Calculate profit margin on parts.*

NEW WORDS

angles
area
Celsius
circumference
cubic measure
decimal numbers
decimal point
degrees
denominator
diameter
digits
dimensions
exponent
factor
Fahrenheit
fractions
height
improper fractions
length
linear measure
number
numerator
percent
pitch
place value
profit margin
proper fractions
protractor
radius
square measure
square units
surface area
units
vertex
volume
width

MATH SKILLS

Basic math skills are essential to the refrigeration, heating, and air conditioning technician. The ability to perform math operations is needed for making accurate measurements, properly replacing parts, installing equipment, and completing work orders and time sheets. This chapter is intended as a refresher course to help you update math skills basic to HVAC work.

READING NUMBERS

A ***number*** is a figure or word indicating a quantity. The numbers 0 to 9 are called ***digits.*** They are used alone, or in combination, to designate "how many." When digits are used in combination with each other, each one is given a special position, called a ***place value***. Although the digits change, these positions *never* vary. Working with numbers is much easier when you understand place value. See Fig. 2-1.

The number shown in Fig. 2-1 reads, *"seven million, six hundred fifty-four thousand, three hundred twenty-one."*

The smallest number, positioned furthest to the **right**, is a single digit from 0 to 9 (in this case, the digit is one). This position is called ***units.*** Other numbers are added to the left of the units position. The next position has a value of *ten*, and the next to the left of that has a value of *one hundred*. Thus, the number 321 is made up of 3 one-hundreds (300), 2 tens (20), and one unit (1), or 300 + 20 + 1 = 321. To make reading and writing large numbers easier, groups of three digits are separated by commas, starting from the units place.

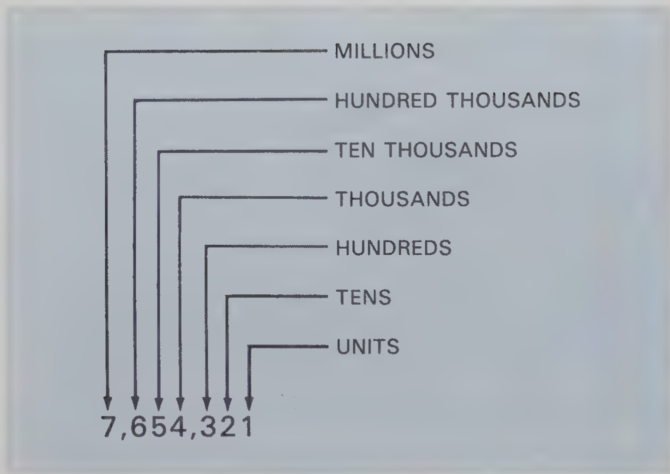


Fig. 2-1. Place value is important in reading whole numbers. Positions of the digits, from right to left, determine their place values.

DECIMAL NUMBERS

Decimal numbers can be thought of as a whole number *plus* any parts, or fractions, of the whole. A ***decimal point*** is used to separate the whole number from the parts. The number of parts is located to the *right* of the decimal. Our money system makes use of decimals. For example, the amount *five dollars and fifty cents* is written **$5.50.** The whole number **5** occupies the unit position, while .50 represents 50 parts of a whole dollar. Since a dollar can be broken down to 100 parts (cents or "pennies"), the decimal number .50 stands for *half* that amount.

Reading decimal numbers

Actually, .50 should be read as "fifty one hundredths," because of place value. Positions of digits appearing to the right of a decimal point are given specific values, just as they are to the left for whole numbers. The place value of the digit farthest to the right indicates how many parts are required to make a whole. See Fig. 2-2.

The number shown in Fig. 2-2 indicates a very small quantity, because the digit farthest to the right **(4)** is located in the *ten thousandths* position. This decimal number reads: one thousand two hundred thirty-four *ten thousandths.* Why? Because when reading decimal numbers, the **position** of the farthest digit to the right indicates how many parts are needed to equal one whole (in this case, 10,000). The actual digits indicate how many parts are available (1234).

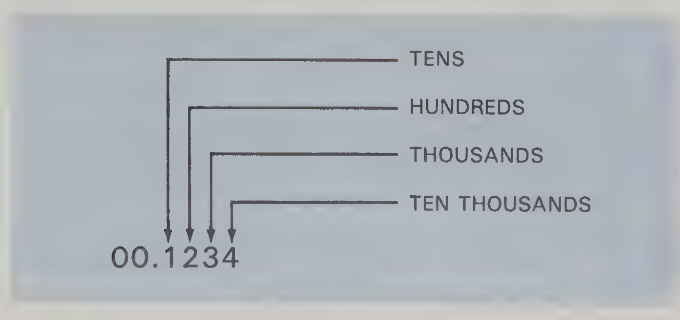


Fig. 2-2. Decimal numbers are read from left to right. Position of a digit to the right of the decimal point determines its place value.

Three digits following a decimal indicates 1000 parts are required to equal one whole. For example, 0.187 is one hundred eighty-seven **one thousandths.** In the same way, 0.75 is seventy-five **one hundredths,** and 0.2 is two **tenths.** Zeros are used as place holders for unoccupied positions: twenty-five **ten thousandths** = 0.0025

Mixed decimal numbers

Decimal numbers, such as 16.75, could be more descriptively referred to as **mixed decimal numbers.** The numbers located to the left of the decimal point gives the number of wholes and the numbers to the right give the fractional parts. The mixed decimal number 16.75 is read *sixteen and seventy-five one hundredths.* The word "and" is used to indicate the decimal point. In industry, the word "point" is often used instead. For example, the number 3.485 is read *three point four eight five.*

FRACTIONS

Fractions are another means of indicating parts of a whole. Fractions are often written with one number above another number, or with the two numbers separated by a diagonal line, as shown in Fig. 2-3. The top number on a fraction (called the ***numerator***) indicates the number of parts available. The bottom number (called the ***denominator***) indicates the number of parts required to make a *whole.*

When you read a fraction, always read the top number (numerator) first, then the denominator. The fraction 5/16 should be read *five-sixteenths.* The numerator **(5)** indicates that there are 5 parts available; the denominator **(16)** indicates that 16 parts are required to make one *whole.*

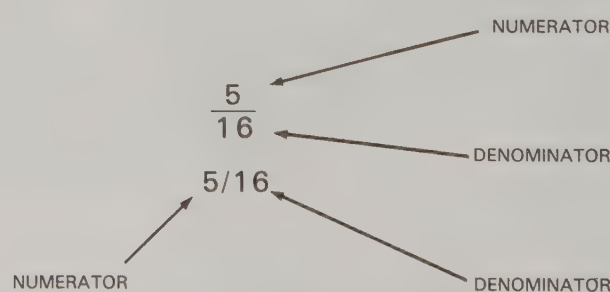


Fig. 2-3. Two different ways to write a fraction: one number above another, or side-by-side with a diagonal separator. The number on top or to the left is called the numerator; the one on the bottom or right is the denominator.

Proper fractions

When the numerator of a fraction is *smaller* than the bottom number, the fraction is termed "proper." For example, the fractions 1/4, 3/8, 1/2, and 7/16 are all *proper fractions*.

Improper fractions

Improper fractions are those in which the numerator is the same or *larger* than the denominator. Examples are: 3/3, 9/8, 7/6, 19/16, 5/4, 8/8. These fractions are called "improper" because the top number is **equal to** or **greater than** the amount required to make a whole. For ease of understanding, improper fractions should be converted to mixed numbers.

When the numerator and denominator are the *same*, the fraction is **equivalent** (equal) to the whole number **1**. Thus, 3/3, 4/4, 5/5, 8/8, and 16/16 are all equivalent to 1.

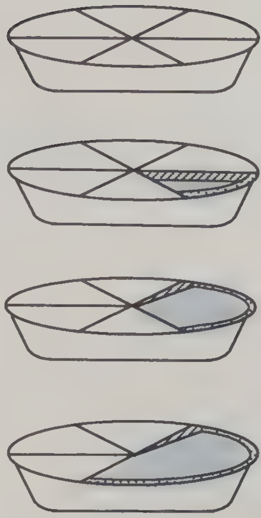


Fig. 2-4. Slices of a pie provide examples of reducing fractions to lowest terms.

Mixed numbers

Mixed numbers are those in which a whole number and a fraction are used together. Examples are: 3 1/2, 6 5/8, 4 2/3, 8 9/16. Mixed numbers are read by inserting the word " and" between the whole number and the proper fraction. Thus, 6 5/8 should be read *six and five-eighths.*

To convert an improper fraction (such as 7/4) to a mixed number, **divide** the numerator by the denominator. Dividing the numerator (7) by the denominator (4) yields a quotient of **1** and a remainder of **3**. The quotient becomes the whole number, and the remainder becomes the numerator. It is placed above the original denominator. Thus, the improper fraction 7/4 can be converted to the mixed number, 1 3/4.

Reducing fractions

Reducing a fraction to its lowest terms means changing the numerator and the denominator to smaller numbers without changing the *value* of the fraction. This is done by dividing the numerator and denominator **by a whole number into which they both can be divided evenly.** For example, 5/10 is equal to 1/2, because both numbers can be evenly divided by 5. In the same way, 25/100 can be reduced to 5/20 by dividing both numbers by 5. This fraction could be further reduced to 1/4 by dividing both numbers by 5. The fraction 1/4 is the fraction 25/100 reduced to *lowest terms*. This means that the fraction cannot be reduced any further. Reducing fractions to their lowest terms makes them easier to understand and work with.

Fig. 2-4 provides examples of how fractions can be reduced. A whole apple pie could be cut into six pieces. This can be expressed in fractional form as 6/6. If one piece (1/6) is removed, 5/6 would remain. If two pieces (2/6) were removed, you could say that **1/3** of the pie is missing. The fraction 2/6 can be reduced to its lowest terms, **1/3,** if you divide the numerator and denominator by 2. If 1/3 of the pie is missing, then 2/3 (4/6 reduced to lowest terms) remain. Even though we are now measuring the pie in different units (thirds, instead of sixths) the units are *equivalent*: either 3/3 or 6/6 still equals a whole pie.

If three pieces of the original six pieces of pie are removed, 3/6 of the pie is gone. This fraction can be reduced to lowest terms, **1/2,** by dividing the numerator and denominator by 3. Once again, the units are equivalent: 2/2, 3/3, or 6/6 all equal a whole pie.

WORKING WITH TIME SHEETS

A practical application of both fractions and decimal numbers is the *time sheet* that is kept as a payroll record of hours or fractions of hours worked.

Sixty minutes equals one hour. For simplicity, many companies "round off" time to the nearest quarter hour. For example, 10 minutes would be rounded to 1/4 hour (15 minutes). Twenty minutes also would be rounded to 1/4 hour. The fractions 1/4, 1/2, and 3/4 can also be expressed in decimal terms, as 0.25, 0.50, and 0.75. This makes it easier to calculate a worker's pay, since decimals are easier to multiply than fractions. If a technician's pay rate is $10.00 per hour, and the technician works 25 hours and 45 minutes, it is much easier to multiply $10.00 by 25.75 than by 25 45/60 (or, in simplest terms, 25 3/4).

If a person works more than 40 hours per week (or 8 hours per day in some states), he or she usually qualifies for *overtime* pay for the extra hours. Overtime pay is usually 1.5 times the regular hourly rate. Pay for work on Sundays or holidays may be *double time,* or 2 times the regular hourly rate.

For example, if a technician's regular pay is $10.00 per hour, the overtime rate would be $15.00 per hour, and the double-time rate would be $20.00 per hour.

The following example shows time worked by a technician earning $10.00 per hour:

Monday: 9.5 hours
Tuesday: 10.25 hours
Wednesday: 8 hours
Thursday: 11.75 hours
Friday: 11.25 hours
Saturday: 9 hours
Total hours worked during week: 59.75
40 regular hours @ $10.00 = $400.00
19.75 overtime hours @ $15.00 = $296.25
Total pay amount for week = $696.25

WORKING WITH DIMENSIONS

Dimensions are measurements of length, width, and depth. Sometimes, the terms *height* or *thickness* are used in place of "depth.") Understanding and working with dimensions is a basic requirement for every technician. New employees are usually assigned to installation projects where such skills are quickly tested. Accuracy in making measurements and in working with dimensions are skills essential to good job performance. They also can affect advancement.

Measurements are made in either the US Conventional or SI Metric systems. The US Conventional system uses basic units of inch, foot, and yard for dimensions; SI Metric uses the millimeter, centimeter, and meter. Most nations of the world, other than the United States, use SI Metric as their measuring system. The units of the two systems are compared below:

1 inch = 2.54 cm (25.4 mm)
1 foot = 30.48 cm (304.8 mm or 0.3048 m)
1 yard = 91.44 cm (914.4 mm or 0.9144 m)

LINEAR (LENGTH) MEASURE

A measurement in one dimension is ***linear measure,*** or the distance from one point to another. ***Length***, width, and depth are all linear measures. So are the radius, diameter, and circumference of a circle, and measurements around the perimeter of any other flat shape. A typical use of the length dimension would be measuring a piece of electrical conduit to fit a specific installation. Tools used to measure length are rulers, steel tape measures, yardsticks or metersticks, chains (for land measurement in *rods* or *meters*), and odometers (for measurements in miles or kilometers). See Fig. 2-5.

1 FOOT	= 12 INCHES
	= 0.3048 METER
1 YARD	= 3 FEET
	= 36 INCHES
	= 0.9144 METER
1 rod	= 16-1/2 FEET
	= 5-1/2 YARDS
	= 5.029 METERS
1 STATUTE MILE	= 5280 FEET
	= 1760 YARDS
	= 320 RODS
	= 1.6093 KILOMETERS

Fig. 2-5. Common linear measuring units in the US Conventional system, and their equivalents in the SI Metric system.

In refrigeration, heating, and air conditioning work, length is normally measured in compound units of feet, inches, and fractions of an inch (for example, 6 ft., 2 1/4 in.) or in meters, centimeters, or millimeters. In SI Metric, compound units are not used. Instead, dimensions are given in decimal fractions (for example: 2.3 m). The abbreviations "ft." for feet, "in." for inches, "m" for meter, "cm" for centimeter, and "mm" for millimeter are commonly used. On architectural drawings using US Conventional measurements, symbols may be used: ′ indicates feet, and ″ indicates inches. For example, a drawing might show a length measurement as:

|←—— 4′ 7-3/16″ ——→|

This measurement in compound units would read: four **feet**, seven and three-sixteenths **inches**. The inches are mixed numbers; therefore, the word *and* is used to separate whole inches from fractional inches.

The equivalent measurement in the SI Metric system would be shown as:

|←—— 140.18 cm ——→|

This measurement would read one hundred forty point one eight centimeters. It could also be stated as 1401.8 mm or 1.4018 m.

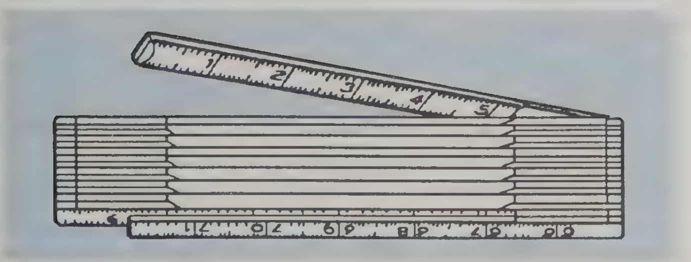
Using measuring tools

Folding rules and measuring tapes are frequently used to obtain accurate measurements. Such measuring devices are illustrated in Fig. 2-6. The ability to read measuring tools accurately is vital to successful job performance. Incorrect measurements waste time and materials, resulting in poor craftsmanship and cost overruns.

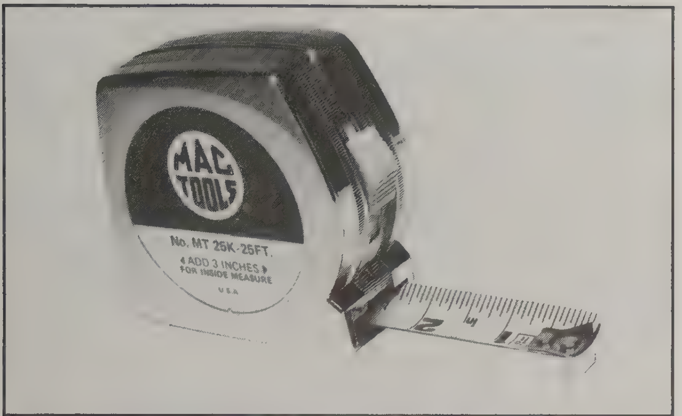
Folding rules are usually 6 feet (approximately 2 meters) long. Tape measures are available in a variety of lengths, ranging from 6 feet to 100 feet. Many have both conventional and metric divisions. The blades of these tape measures are almost always steel, Fig. 2-7. In the 50 ft. and 100 ft. (15 m and 30 m) lengths, nonmetallic blades reinforced with fiberglass are sometimes offered. Also available are tapes that contain a battery and small light bulb for reading measurements in dimly lighted areas, such as attics and basements.

Reading a US Conventional ruler

Each foot on a standard ruler or tape is calibrated to contain exactly 12 inches, numbered from 1 to 12, as shown in Fig. 2-8. Measurements in inches can sometimes be expressed as fractions of a foot. A measurement of six inches, for example, can also be read as 1/2 foot. Since one foot contains 12 inches, or 12/12, six inches equals 6/12. As described earlier in this chapter, 6/12 can be reduced to its lowest terms, 1/2. In the same



A



B

Fig. 2-6. Common measuring devices. A–Carpenter's folding wood rule. B–Steel measuring tape. (Mac Tools, Inc.)

way, 4 inches equals 4/12, which reduces to 1/4 foot, and 9 inches equals 9/12, which reduces to 3/4 foot. See Fig. 2-8.

Sixteenths. Generally, an inch is divided into sixteen parts, called sixteenths. Therefore, one inch equals 16/16, as shown in Fig. 2-9. Because sixteenths are tiny segments, very small lines are used to indicate these divisions.

Eighths. Two very small divisions equal 2/16, which is reduced to lowest terms as 1/8. As shown in Fig. 2-10,

Fig. 2-7. Measuring tapes, such as this 100-foot-length model, usually have steel blades for durability. Some long tapes, however, have nonmetallic blades. (Mac Tools, Inc.)

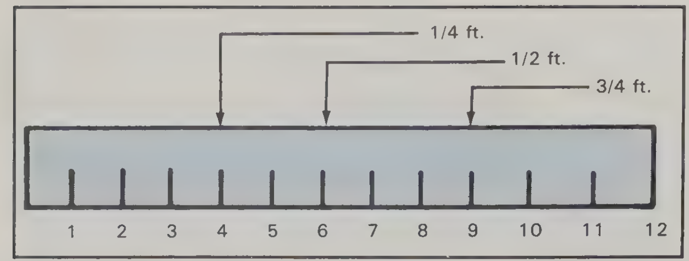


Fig. 2-8. In the US Conventional system, each foot of a ruler or tape is divided into 12 equal inches. Measurements can also be expressed as fractions of a foot, as shown.

Fig. 2-9. Sixteenths are the smallest division of an inch shown on most rulers or measuring tapes.

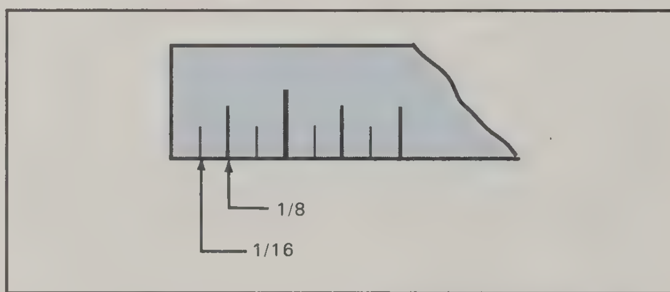


Fig. 2-10. One-eighth inch is equivalent to two-sixteenths. Eighth marks on measuring devices are slightly longer or darker than sixteenth marks.

the mark for **eighths,** is slightly darker and longer than the one for sixteenths. The longer eighth mark indicates that even-numbered sixteenths can be reduced to eighths. This does not change the total value of the reading, because it requires 8/8 to equal one inch.

Fourths. Two eighths (or four sixteenths) equal one-fourth of an inch. The longer mark used to divide the inch into fourths is shown in Fig. 2-11. All even-numbered eighths can be reduced to fourths. Again, reducing a number to its lowest terms does not change the total value, because it requires 4/4 to equal one inch.

Halves. The **half-inch** mark is longer than the lines for the fourths, eighths, or sixteenths divisions, as shown in Fig. 2-12. Reducing 8/16, 4/8, or 2/4 to 1/2 does not change the total value, since it requires 2/2 to equal one inch.

Reading an SI Metric ruler

Metric rulers usually show only two divisions, *centimeters* and *millimeters*. Measuring tapes normally indicate *meter* divisions, as well.

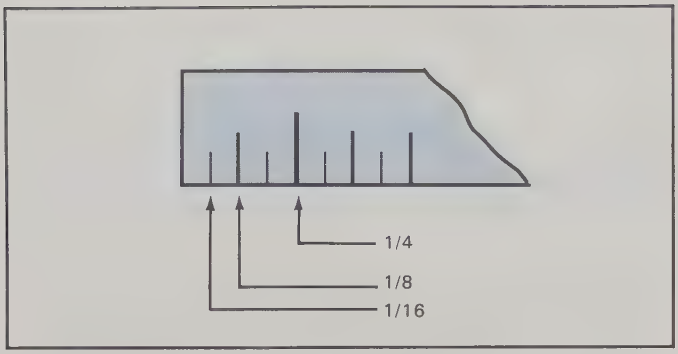


Fig. 2-11. One-fourth inch is equivalent to two eighths or four sixteenths. The fourth marks are longer and darker than eighth or sixteenth marks.

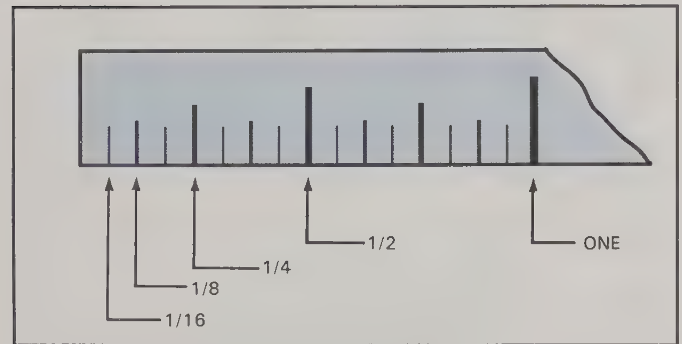


Fig. 2-12. Half-inch marks are longer and darker than fourth-inch marks, but shorter and usually less dark than marks indicating each full inch. A number is usually placed at each inch mark, as well.

The SI Metric system is based on units of 10. The smallest unit on the ruler is the millimeter. As shown in Fig. 2-13, ten millimeters make up one centimeter, which is set off with a longer line. (Approximately 2 1/2 centimeters equal one inch.) Ten centimeters, in turn, make up a *decimeter* (this unit is not widely used, and is seldom even marked on rulers or tapes.) Ten decimeters make up one **meter**. One hundred centimeters ("centi" means hundred) or 1000 millimeters ("milli" means thousand) are also equal to one meter.

Rough measurements

Rough measurements are distance estimates that are simpler to make, but less accurate, than measurements with a ruler or tape. Rough measurements are often satisfactory for quick estimating of job requirements, but should be as accurate as possible. With proper preparation, you can use various body parts as standards for obtaining rough measurements.

Hand measurements. Measure from the base of the palm to the end of each finger. Unless you have unusually small hands, one of these measurements should be very close to 6 in. (152.4 mm) Also, measure across the palm and remember the distance. Hand measurements are useful for short lengths of copper tubing.

Body height and arms. Measure and remember your height (floor to top of head) and your height with arm and fingers extended upward. Also measure and remember the distance from floor to your belt line. With with both arms fully extended sideways, have someone measure the distance from fingertip to fingertip. Also, with arm extended forward, measure from fingertip to the middle of your chest. These measurements can become very useful.

Stepping off distances. You can step off yards or meters quite accurately with some preparation and practice. To perfect this time-saving method of rough measurement, lay a yardstick or meterstick on the floor, and line up the heel of your left shoe with the end of the stick nearest you. Next, place your right shoe in front of the left shoe, touching heel-to-toe. Finally, move the left shoe in front of the right shoe. Again, touch heel-to-toe. Note the measurement on the stick next to the toe of your left shoe: it should be near the end of the yardstick or meterstick. For many adults, three shoe-lengths will be approximately equal to a yard or meter. The remaining distance between the toe of your left shoe and the end of the stick will be a guide for the amount of space to allow between shoe-lengths when "stepping off" a measurement. Try stepping off a room or hallway and then check measurement with a tape. Practice until some degree of accuracy is obtained. Accurate stepping off can save much time and trouble.

SQUARE (AREA) MEASURE

A measurement of two dimensions, length and *(width)*, is known as *square measure*. It gives you ***surface area.*** To find the area of a rectangular surface,

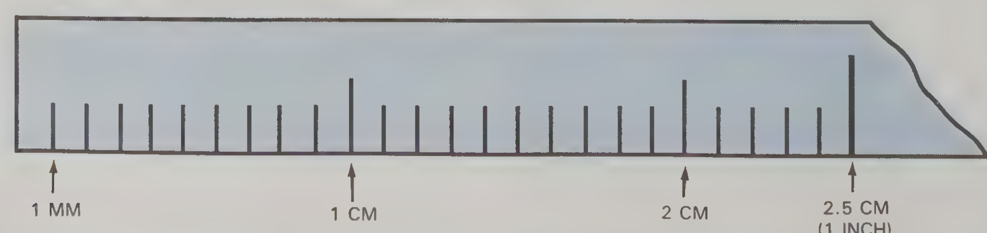


Fig. 2-13. On a meter stick or metric ruler, each centimeter is divided into 10 millimeters. This ruler shows both US Conventional and SI Metric scales for comparison. Note that 1 inch equals approximately 2.5 centimeters (more precisely, 2.54 cm).

multiply the first dimension (length) by the second dimension (width). See Fig. 2-14. To find the area of a triangle, multiply the length by the width, then divide by 2. Finding the area of a circle is covered later in this chapter.

Surface area measurements aid in placing equipment and determining the amount of paint or tile required to cover floors, walls, and ceilings.

When finding surface area of any shape, the answer is *always* expressed in *square units:* square inches or square feet, square centimeters or square meters, and so on. It is interesting that acres and hectares are automatically square measures. There is no need to use the word "square" when referring to land measure in acres or hectares.

Reading exponents or power numbers

An ***exponent*** or **power** is an abbreviation used to indicate a multiplication process. The exponent is a numeral that is placed above and to the right of a *base* number. For example, in the number 10^2, the numeral ^{2} is an exponent or power number. It tells how many times the base number (also called a *factor*) is used for multiplying. Thus, 10^2 actually means 10×10. The factor (10) was used **twice.** In math terms, a number that is multiplied by itself (10×10) is said to be "squared." Thus, 10^2 can be read as *10 squared,* or *10 to the second power.*

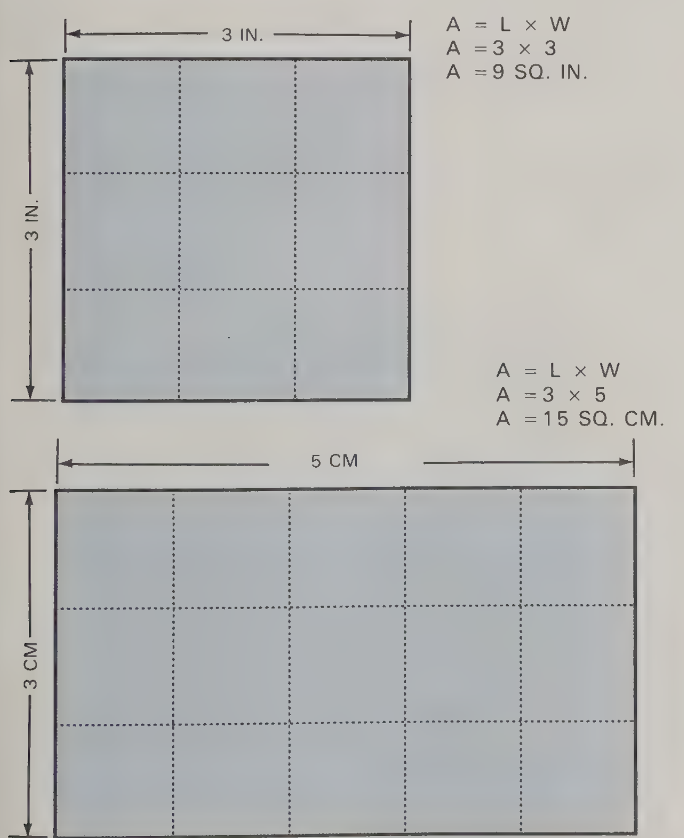


Fig. 2-14. To find surface area, multiply length by width. The result is expressed in square units. In this illustration, one area is in square inches, the other in square centimeters.

Exponents can be any number, and can be used to express large whole numbers. For example, 20^5 means the factor 20 must be used five times, or $20 \times 20 \times 20 \times 20 \times 20$. The result? $20^5 = 3{,}200{,}000$. See Fig. 2-15.

$$
\begin{array}{lcr}
20^2 & = & 20 \\
 & & \underline{\times 20} \\
 & & 400 \\
20^3 & = & \underline{\times 20} \\
 & & 8{,}000 \\
20^4 & = & \underline{\times 20} \\
 & & 160{,}000 \\
20^5 & = & \underline{\times 20} \\
 & & 3{,}200{,}000
\end{array}
$$

Fig. 2-15. An example of using exponents, showing how they can be used to express large numbers.

Converting to a common unit

A mixture of feet and inches cannot be used when multiplying measurements to find surface area. Neither can a mixture of millimeters and centimeters, or centimeters and meters. All measurements must be converted to the same value (a *common unit*) before multiplying. See Fig. 2-16.

For example, to find the area of a floor measuring 10′6″ x 1′24″, you must change the dimensions to a common unit, **inches.** Since there are 12 inches to a foot, multiply the number of feet by 12, then add the inches:

$$10'6'' = (10' \times 12'' = 120'' + 6'' = 126'')$$
$$12'4'' = (12' \times 12'' = 144'' + 4'' = 148'')$$

Multiplying 126 in. × 148 in. gives you the surface area: 18,648 sq. in. Since areas this size are usually measured in square feet, however, you have to convert square inches to square feet. This is done by dividing by 144. Each square foot contains 12 in. by 12 in., or 144 sq. in. Dividing 18,648 by 144 gives you the surface area, 129.5 sq. ft.

AREA MEASUREMENT (US CONVENTIONAL)		
1 square foot	=	100 square millimeters
1 square yard	=	9 square feet
SI METRIC		
1 square centimeter	=	100 square millimeters
1 square meter	=	10,000 square centimeters

Fig. 2-16. Common measuring units for area in both US Conventional and SI Metric systems.

The same problem can be solved by converting all measurements to feet and the decimal equivalents of fractions of feet: 10′6″ equals 10.5 feet, and 12′4″ equals 12.3333 feet.

$$10.5 \times 12.3333 = 129.4996 \text{ sq. ft.}$$
(rounded to 129.5 for convenience).

Converting *metric* dimensions to a common unit is simpler, since all metric units are multiples of 10. For example, imagine that you have to find the area of a countertop that is 85 cm wide and 2 m long. You first have to put the measurements into a common unit: either convert the 2 m dimension to centimeters, or the 85 cm dimension to a decimal fraction of a meter. First, we'll use centimeters as the common unit. Since there are 100 centimeters in each meter, multiply 2 times 100. The common unit (cm) lets you simply multiply length times width: $85 \times 200 = 17{,}000$ square centimeters (usually written as 17 000 cm^2). To convert this figure to square *meters,*, divide by 10,000, (100 cm × 100 cm = 10 000 cm^2 or 1 square meter). If you divide 17 000 cm^2 by 10 000 cm^2, the result is 1.7 m^2.

You can achieve the same result, in just one step, by converting 85 cm to its equivalent decimal fraction, .85 m, and multiplying: $.85 \times 2 = 1.7\ m^2$

Math formulas

Formulas are used by mathematicians in much the same way that recipes are used by cooks. The formula explains how to achieve the correct result. Unless a formula is used frequently, it can be difficult to remember. Seldom-used formulas should be placed in a file for reference as needed.

Knowing how to read and use formulas is important. Symbols and abbreviations are used to save space. For example, many formulas do not include an "×" to indicate multiplication. The × is "understood." Functions other than multiplication are indicated by a symbol. An example of how × is eliminated is shown by the formula used to compute the area of a circle: $A = (\pi)r^2$. This formula means:

Area = 3.1416 (value of π) × radius × radius.

Special rules govern the *order* (first, second, and so on) in which operations within a math formula are performed.

1. Sections enclosed within ( ) are done first. If there are ( ) *within* ( ), the operations are done from the innermost set outward.
2. Base numbers must be multiplied to the specified power.
3. Multiplication and division are performed in order given, reading left to right.
4. Addition and subtraction are performed in order given, left to right.

Memorizing the phrase, "**P**lease **E**xcuse **M**y **D**ear **A**unt **S**ally" provides a simple aid for remembering order in which functions are performed. The first letter of each word provides the clue:

- **P**arentheses
- **E**xponents
- **M**ultiply
- **D**ivide
- **A**dd
- **S**ubtract

Working with circles

Measuring and cutting circles are tasks that occur fairly often in heating and cooling work. Terminology and measurements must be accurate. A circle is measured by a straight line across the widest part of its perimeter. This line is called the ***diameter.*** A line from the center of the circle to its perimeter (half the diameter) is called the ***radius.*** See Fig. 2-17. A practical example of using radius and diameter is finding the size of a fan blade. Measuring from the center of the hub to the outside edge of one blade, as shown in Fig. 2-18, will give

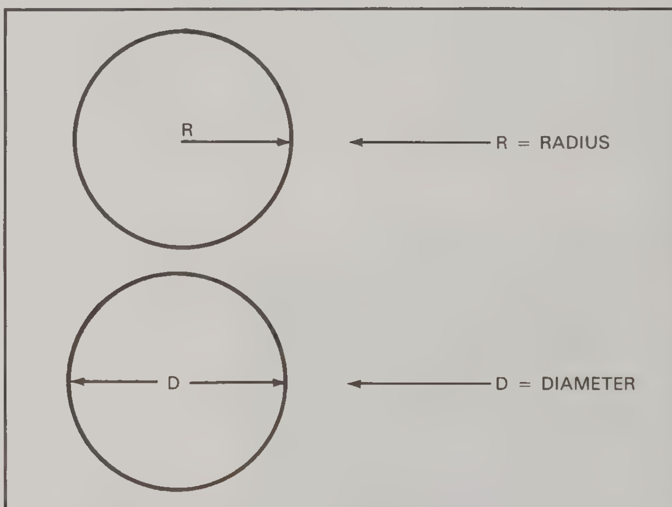


Fig. 2-17. The diameter is the distance across the widest part of a circle. The radius is half the diameter.

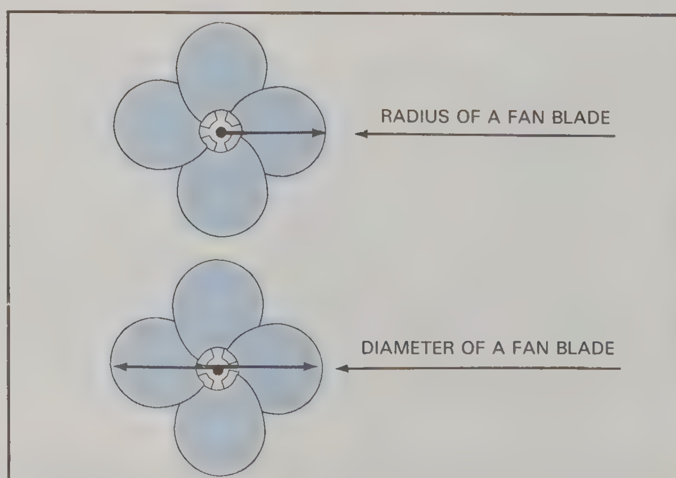


Fig. 2-18. Finding the radius and the diameter of a fan blade.

you the radius. Then, just multiply by 2 to find the diameter.

Finding the ***area*** of a circle is sometimes necessary. It is used, for example, to measure piston displacement or to determine the capacity of a liquid cylinder. The most common method or formula for finding the area of a circle is:

$A = \pi r^2$

where A = area

p = 3.1416

r = radius

Using this formula, you can find the area of a circle whose radius is three inches as follows:

$A = \pi r^2$

$A = 3.1416 \times 3^2$

$A = 3.1416 \times (3 \times 3)$

$A = 3.1416 \times 9$

A = 28.2744 sq. in.

CUBIC (VOLUME) MEASURE

Cubic measure, using the three measurements of ***height***, length, and width, makes it possible to determine ***volume.*** The difference between area and volume is the need for another measurement, height, as shown in Fig. 2-19.

Volume measurements are necessary, for example, when figuring the number of cubic feet of space in a room or home being air-conditioned. Volume measurements are also necessary for such tasks as figuring concrete needed for slabs, determining piston displacement, and finding the capacity of a cylinder.

To find the volume of a rectangular-shaped solid, multiply the three dimensions together. The formula is:

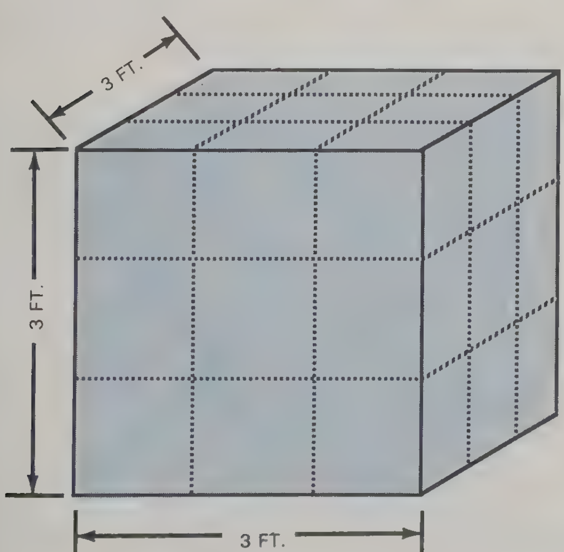


Fig. 2-19. By measuring height as well as length and width, you can compute the volume of an object, such as this cube. In this example, 3 ft. × 3 ft. × 3 ft. = 27 *cubic* ft. The volume computation could also be expressed as 3^3 or as ''three cubed.''

$V = L \times W \times H$. Volume is *always* expressed in **cubic** terms: cubic inches (cu. in.), cubic centimeters (cm^3), cubic feet (cu. ft.), cubic yards (cu. yds.), or cubic meters (m^3).

1 cu. in. = 16.387 cm^3

1 cu. ft. = 1728 cu. in. = 28 316.846 cm^3

1 cu. yd. = 27 cubic feet (cu. ft.) = 0.7645 m^3

A perfect cube would have identical measurements in all three dimensions. For example, a cube measuring 12 in. in all three dimensions would have a volume of 1728 cu. in. (12 × 12 × 12 = 1728). This cube can be expressed as 12^3, which can be read as "12 cubed," or "12 to the third power." Therefore, 12^3 equals 1728.

Finding volume

The ability to work with numbers can assist your development from a helper's job to eventually becoming a master technician who draws top wages. Throughout your workday, situations will arise in which math skills are needed. For example, a concrete pad must be poured before you can place an outdoor condensing unit for a residential air conditioning installation. What is the volume of a concrete pad measuring 4 feet long, 3 feet wide, and 6 inches deep?

$V = L \times W \times D$

$V = 4 \times 3 \times 0.5$ (1/2 foot = 0.5 in)

$V = 12 \times 0.5$

V = 6 cu. ft.

An 80-pound bag of concrete mix will make 2/3 cu. ft. (0.66 cu. ft.) of concrete. How many bags will be needed to pour the above pad?

$6 \div 0.66 = 9$ bags

Volume of a cylinder

Finding volume of a *cylinder* involves three dimensions. Since a cylinder is round, the area of a **circle** is found and multiplied by the height dimension. The formula for finding the volume of a cylinder is: $V = \pi r^2 H$. For example, find the volume of a cylinder that is 3 inches in diameter and 5 inches tall, as shown in Fig. 2-20:

$V = \pi r^2 H$

$V = 3.1416 \times (1.5 \times 1.5) \times 5$ (diameter = 3 in., so radius = 1.5 in.)

$V = 3.1416 \times 2.25 \times 5$

$V = 3.1416 \times 11.25$

V = 35.343 cu. in.

With this information, it is possible to determine the amount of vapor that a compressor can compress in a given period of time (usually, they are rated in cubic feet per minute, or CFM). Assume that the cylinder is on a two-piston compressor, operating at 1800 revolutions per minute (RPM). Since this compressor has two pistons, the cylinder volume must be doubled:

35.343 × 2 = 70.686 cu. in.

Next, multiply the volume by the RPM. This will result in a cubic *inches* per minute figure:

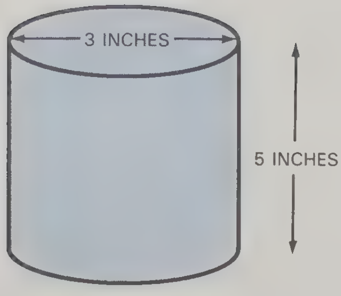


Fig. 2-20. To find the volume of a cylinder, first find the area of a circle, then multiply by the height dimension.

70.686 × 1800 = 127,234.8 cu. in./min.

Finally, convert cubic inches per minute to cubic feet per minute. (Since 1728 cu. in. = 1 cu. ft., divide by 1728)

127,234.8 ÷ 1728 = 73.63 cu. ft./min.

WORKING WITH TEMPERATURE SCALES

Although the ***Fahrenheit*** (°F) temperature scale is most common in the United States, the ***Celsius*** (°C) scale is the one used in almost all other countries. Technical literature may use either scale, and sometimes will include values in both. While you are most likely to use the Fahrenheit scale in refrigeration, heating, and air conditioning work, you should also be able to use the Celsius scale. Sometimes, you will have to convert Fahrenheit temperatures to Celsius temperatures, or vice-versa. See Fig. 2-21 for scale comparisons.

CONVERTING TEMPERATURE READINGS

There are two methods used for converting Fahrenheit to Celsius, or Celsius to Fahrenheit. One involves using fractions; the other uses decimals. Either method will yield the correct answer, but the decimal method is easiest to use:

Fahrenheit = 1.8 × Celsius + 32

Celsius = Fahrenheit ÷ 1.8 - 32

To convert a temperature of 40°C to Fahrenheit:

°F = 1.8 × 40 + 32

°F = 72 + 32

°F = 104

To convert 104°F to Celsius:

°C = 104 - 32 ÷ 1.8

°C = 72 ÷ 1.8

°C = 40

It is worth noting that the Fahrenheit and Celsius scales read the same at -40 degrees! (You can prove it by using the above formulas.)

ANGLES AND DEGREES OF A CIRCLE

Angles and degrees of a circle are important when selecting tubing and pipe fittings. The angle of a fan blade is a critical factor for proper air flow.

By definition, the ***circumference*** (distance around) a circle is divided by 360 equal angles. The measure of each angle is defined as 1 ***degree***. See Fig. 2-22. A straight line from 360° to 180° would cut the circle in half. A ***protractor*** is an instrument used to measure degrees and angles of a circle. A protractor is a half-circle, marked from 0 to 180 degrees. See Fig. 2-23.

An ***angle*** is formed by two lines drawn from the same starting point. The starting point may be thought of as the dead center of a circle and is called the ***vertex.*** One line is drawn from zero degrees to the vertex, and the other line extends from the vertex to any degree mark on the circle. The number of degrees between the lines intersecting the circle becomes the **degree of angle.**

A 90° angle (often referred to as a "right angle") is best illustrated by the hands of a clock reading 3

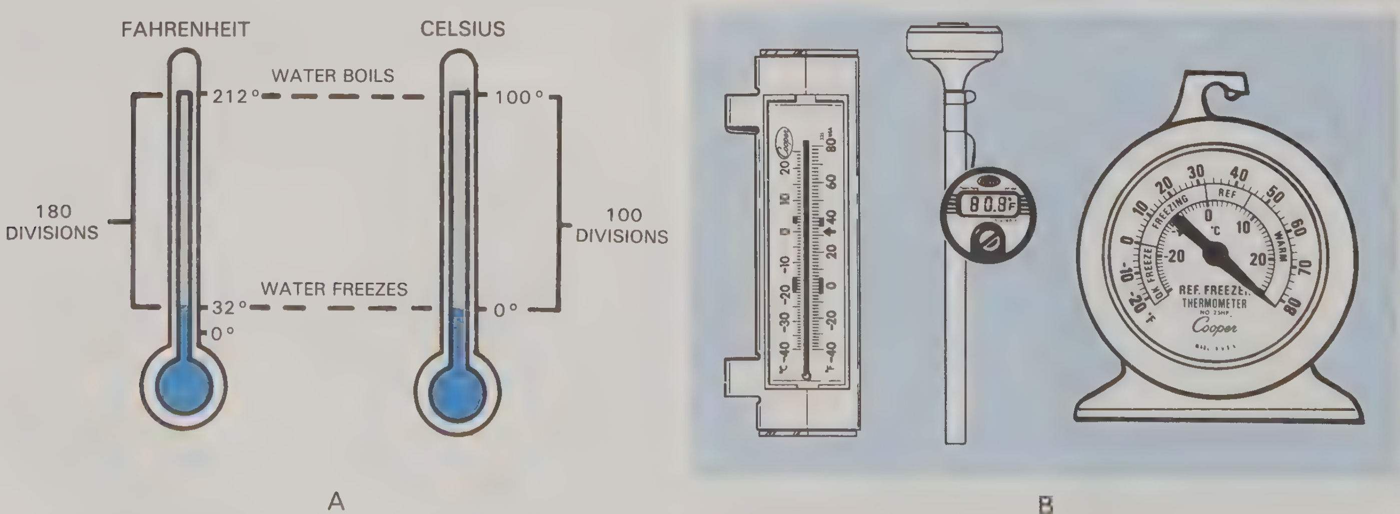


Fig. 2-21. Temperature scales. A–The Fahrenheit and Celsius temperature scales compared. Note that the Fahrenheit scale has almost twice as many divisions as the Celsius scale between freezing and boiling points. B–Different types of thermometers. Some show both scales.

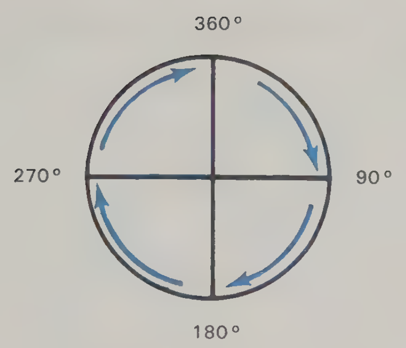


Fig. 2-22. A circle is divided into 360 degrees.

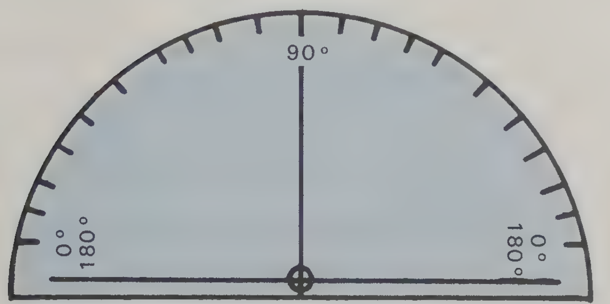


Fig. 2-23. A protractor is used to measure angles and the degrees of a circle.

o'clock. See Fig. 2-24. The small hand points to the "zero" (3 on the clock face) and the large hand points to "90" (12 on the clock face). Therefore, the degree of angle is 90.

A 45° angle is halfway between 0 and 90. It takes *two* 45° elbow fittings to equal *one* 90° elbow fitting. See Fig. 2-25. Also, two 90° elbows make a U-bend (also called a U-turn).

All fan blades are twisted to a particular degree of angle called a ***pitch.*** Each blade must have the same pitch or angle for efficient operation. The pitch is an important factor in determining the volume of air moved by the fan. All else being equal, a fan with blades at a 20° pitch will not move as much air as one with blades at a 33° pitch. The pitch is usually stamped on one blade.

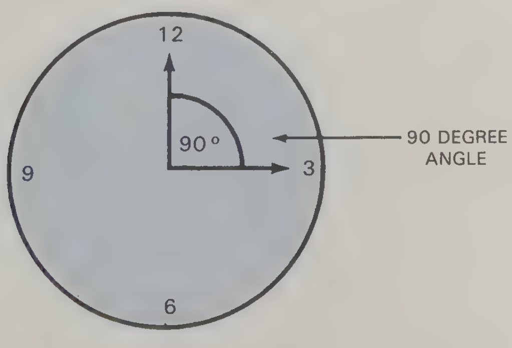
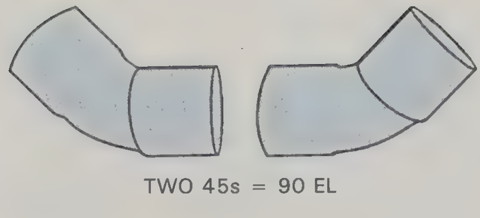


Fig. 2-24. Ninety degrees is a quarter-circle. Clock hands in the 3 o'clock position, as show in this illustration, form a 90° angle.



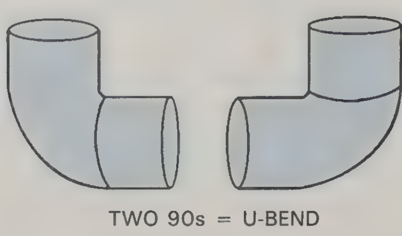


Fig. 2-25. Two 45° elbows can be combined to make a 90° elbow, or ''ell''. Two 90° elbows can be combined to make a U-bend.

USING PERCENT FOR PROFIT MARGIN

Parts and supplies used to make repairs are charged to the customer, with a ***profit margin*** included in the price. The profit margin, or **markup,** is the difference between cost and selling price. The difference is created by increasing cost price by a certain **percentage.**

FINDING PERCENTAGE

One ***percent*** of a number means 1/100 of that number, six percent means 6/100, and so on. The symbol % stands for the word "percent." Thus, 10 percent is written 10%, 25 percent as 25%, and so on. The symbol % does the work of *two decimal places,* or hundredths. For example, 6% = .06; 25% = .25; 50% = .50; 100% = 1.00.

Since percent means "hundredths," the whole of any number contains 100% of itself. Thus 100% of 20 is 20. If a 100% profit margin was applied to a part, for example, the customer would be charged $40.00 for a part that cost the seller $20.00. With a profit margin of 25%, one-quarter of the cost price is added to obtain selling price. Since 25% of 20 is 5, the item's selling price would be $25.00.

An easy method of figuring selling price is to consider cost price as 100%, and add the percent of markup. Thus, a 25% profit margin becomes 125% of cost. A 50% profit margin becomes 150% of cost, and 100% profit margin becomes 200% of cost. To change percent to decimals, drop the % sign and move (or add) a decimal point two places to the left. This means that 125% = 1.25, 150% = 1.50, and 200% = 2.00.

As an example of how a selling price is determined with this method, consider a part with a base cost of $23.50. The desired profit margin is 25%, so the selling price is figured by multiplying base cost ($23.50) × 1.25. The result is a selling price of $29.38.

SUMMARY

The ability to perform basic math operations is necessary in all phases of the refrigeration, heating, and air conditioning trade. This chapter was intended as a refresher to help you remember the skills needed to work with numbers. Later chapters will use mathematics, as needed, to explain and prove how various system components operate.

Being able to apply good basic math skills will prevent mistakes and leads to early advancement. The logical, step-by-step thought processes required to perform math operations are valuable. Math is often used to explain *why* and *how* a system is repaired.

All technicians must have the ability to work with decimals, fractions, and percentage. Understanding dimensions, measurements, and how to read a ruler (both US Conventional and SI Metric) are basic requirements of every technician. Such tasks as completing time sheets and work orders, pricing parts, and keeping inventory and mileage records involve the use of math skills.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Decimals are used to separate whole numbers from __________.
2. How would you read the number 6.435? (Do not use the word "point.")
3. The bottom number of a fraction is the:
   a. Elevator.
   b. Denominator.
   c. Designator.
   d. Numerator.
4. True or false? The fraction 9/5 is an improper fraction.
5. Inch, foot, and yard are units of length in the __________ system of measurement.
6. There are ________ inches in one foot, and __________ centimeters in one meter.
7. There are ________ sixteenths in one inch.
8. True or false? The fractions 24/32, 12/16, 6/8, 3/4 all represent the same value.
9. To find __________ of a rectangle, length and width measurements must be made.
10. How would you read the number 5^2? What does it mean?
11. Half the distance across the widest part of a circle is called the __________.
12. Volume of a rectangular-shaped solid is computed by multiplying length times width times __________.
13. The value of π is
    a. 2.54
    b. 1.666
    c. 3.1416
    d. 0.9865
14. What is the formula for converting Celsius to Fahrenheit?
15. What is the selling price of a part that cost $36.84, if the profit margin (markup) is 50%?

Chapter 3

FASTENERS

After studying this chapter, you will be able to:
- *Recognize different thread forms.*
- *Understand thread terminology.*
- *Demonstrate proper use of taps and dies.*
- *Identify screw types and sizes.*
- *Identify and correctly use bolts, nuts, and washers.*
- *Identify and use masonry anchors.*
- *Understand proper use of the major types of fasteners.*

NEW WORDS

American National Standard Thread
blind hole
blind rivet
bolt extractor
bolts
cap screws
crest
die
International Thread
machine screw
major diameter
masonry anchors
minor diameter
Molly bolt
nuts
root
screw thread
screws
set screws
tap
thread angle
threaded rod
threads per inch
toggle bolts
Unified Thread
washers

THREADS

Before you can successfully use the various types of bolts and screws, you must be familiar with the different types of threads used on these fasteners. The beginning technician should know and understand:
- Different thread forms.
- Standards for each thread form.
- Thread measuring methods.
- How to determine the proper tap-drill size for a screw thread.

This information is not difficult to find or understand. Differences in threads must be understood to successfully use fasteners.

THREAD TERMINOLOGY

A ***screw thread*** is a helical ridge of uniform section formed inside of a hole (such as a nut) or on the outside of a fastener (such as a screw or bolt). Threads cut on an outside surface are referred to as *external;* those cut on an inside surface are called *internal.*

Terms describing parts of the screw thread are described below and shown in Fig. 3-1.
- The ***major diameter*** is the widest measurement from the outside edges of the threads.
- The ***minor diameter*** is the smallest diameter, measuring from the inside of the threads.
- The ***root*** is the bottom area of two adjoining threads.
- The ***crest*** is the top edge of two adjoining threads.
- The ***threads per inch*** is determined by counting the number of crests (or roots) per inch of threaded section.
- The ***thread angle*** is the V-angle of the threads. The sides of the threads normally form an angle of 60°.

STANDARD THREAD FORMS

Of the standard thread forms, the most widely used in industry today in North America are the **American National** and the **Unified** forms. They are popular be-

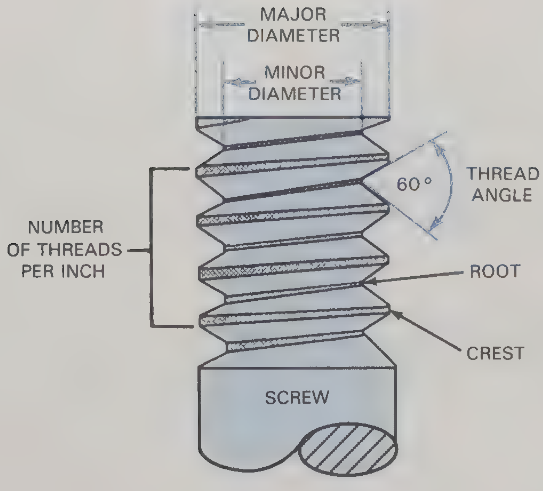


Fig. 3-1. Parts of the screw thread. The number of threads per inch determines whether a thread is Coarse or Fine.

cause they can be mass-produced easily and economically. Another standard form that is coming into widespread use is the **International Thread,** also known as the **ISO Metric Thread Series.**

AMERICAN NATIONAL STANDARD

American National Standard Thread consists of three main series of threads. They are the **National Fine** (abbreviated as NF), **National Coarse** (NC), and **National Pipe** (NP) threads.

National Fine has a greater number of threads per inch than National Coarse, and the threads are not as deep as National Coarse threads. Both NC and NF threads maintain constant major and minor diameters. National Pipe threads , however, are *tapered* (sloped) 1/16 inch in diameter for every one inch of threaded length. This taper causes the threads to bind together, making an increasingly tight seal as a pipe fitting is tightened. This means that pipe threads tend to be self-sealing by the pressing together of the V-threads as fittings are connected.

When using fasteners, you must be certain that all components have the *same style* of threads. For example, you cannot screw a NF nut onto a NC bolt! See Fig. 3-2. Attempts to force mismatched threads to mate can severely damage threads and render the fastener useless. Damaged threads can sometimes be dressed by rethreading them with a tap or die of the proper size.

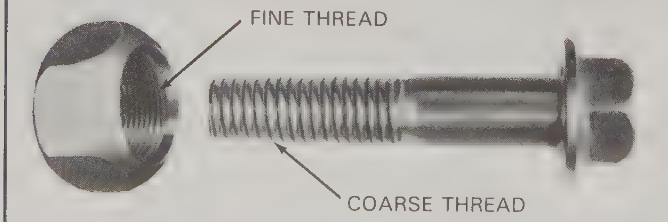


Fig. 3-2. Threads of different types and styles cannot be used together. The Fine thread on the nut will not mate properly with the Coarse thread on the bolt. (RB&W Corporation)

National Coarse (NC) threads are widely used to make bolts, nuts, and screws where quick assembly is desired in materials such as cast iron, steel, bronze, brass, aluminum, and magnesium. The National Fine (NF) thread series is also used in the manufacture of nuts, bolts, and screws. NF threads are usually specified in situations where the thread engagement is short or where the internal threads are cut into a thin-walled material. National Pipe Threads (NPT) are used in the assembly of steel pipe and cast iron fittings for water lines and natural gas lines. Some heavy duty electrical conduit also uses NPT.

UNIFIED SCREW THREADS

The American National screw thread form was the standard in the United States for many years. However, there were industry leaders who advocated a thread system that would permit interchangeability of screw threads with other countries, especially those following British standards.

The **British Standard Whitworth** thread would not interchange with the American National thread. American National had a thread angle of 60° and the roots and crests were slightly flattened. The Whitworth thread had a thread angle of 55°, with roots and crests that were rounded.

During World War II, England and Canada agreed to change the Whitworth thread angle to 60°, but retain the rounded crests and roots. This new thread, called the *Unified Thread*, was interchangeable with American National threads. Since that time, American National Fine (NF) has been interchangeable with Unified National Fine (UNF), as have been National Coarse (NC) and Unified National Coarse (UNC).

The **Unified Thread** is now the standard thread, but the American National coarse and fine-thread series will continue to be seen on gauges, tools, and blueprints for a number of years. For this reason, the technician should be familiar with both systems.

OTHER THREAD FORMS

International Thread is a standardized metric thread used in most parts of the world. The International Standards Organization (ISO) metric thread has a 60° angle with slightly flattened roots and crests. Use of this thread form is growing in North America. The main difference between International Thread and the Unified Thread series is the depth of thread. They are not interchangeable.

The **American National Acme** thread has a 29° angle and is used for feed screws, jacks, and vises.

The **Brown and Sharpe Worm** thread also has a 29° angle, but the depth of the root is greater than that of the Acme thread. This thread is used to mesh with worm

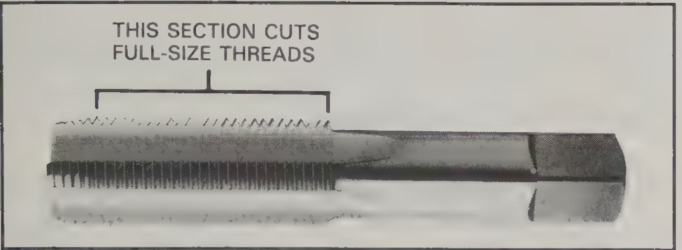


Fig. 3-3. A taper tap is designed for easy starting. (Triumph Twist Drill Co.)

gears and transmit motion. A self-locking feature makes it usable for winches and steering mechanisms.

CUTTING INTERNAL THREADS

A *tap* is a tool used to cut threads inside a hole. Taps are made of special hardened steel and threaded for about half their length. The threaded grooves are called **flutes,** and the edge of each thread forms a cutting edge.

Taps are available in three types; **taper, plug,** and **bottoming.** On the taper tap, Fig. 3-3, the first six threads are tapered for easy starting. Fig. 3-4 shows a plug tap, the most common, on which only three or four threads are tapered. The bottoming tap, Fig. 3-5, is not tapered. It is used to cut threads to the bottom of a hole. The size is stamped on the unthreaded portion of the tap, called the **shank**. This number tells the outside diameter and the number of threads per inch.

Prior to using a tap, a pilot hole must be drilled into the workpiece. *The size of the pilot hole is critical.* The hole must be smaller than the tap's outside diameter to allow for cutting of full threads inside the hole. The proper pilot hole size (drill size) can be determined by consulting tables like those shown in Figs. 3-6 through 3-8.

Once the pilot hole has been drilled, insert the tap and be sure it is aligned properly with the work surface. If the tap is large, use a wrench to turn it. Small taps are

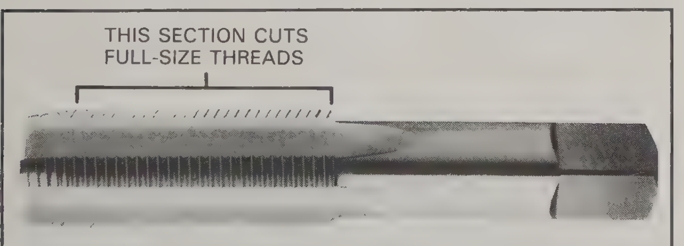


Fig. 3-4. A plug tap is the most common type. (Triumph Twist Drill Co.)

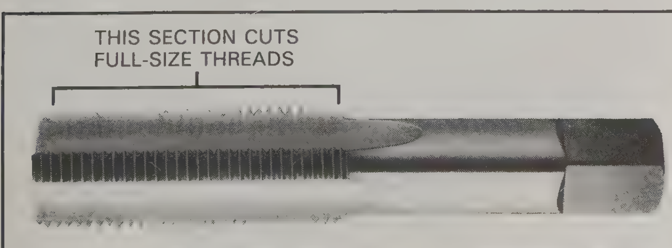


Fig. 3-5. A bottoming tap is used to cut threads to the bottom of a hole. (Triumph Twist Drill Co.)

NATIONAL COARSE THREADS		
TAP SIZE	THREADS PER INCH	DRILL SIZE
#5	40	#38
#6	32	#36
#8	32	#29
#10	24	#25
#12	24	#16
1/4''	20	#7
5/16''	18	F
3/8''	16	5/16''
7/16''	14	U
1/2''	13	27/64''
9/16''	12	31/64''
5/8''	11	17/32''
3/4''	10	21/32''
7/8''	9	49/64''
1''	8	7/8''

Fig. 3-6. Table of tap and drill sizes for National Coarse (NC) threads.

NATIONAL FINE THREADS		
TAP SIZE	THREADS PER INCH	DRILL SIZE
#5	44	#37
#6	40	#33
#8	36	#29
#10	32	#21
#12	28	#14
1/4''	28	#3
5/16''	24	I
3/8''	24	Q
7/16''	20	25/64''
1/2''	20	29/64''
9/16''	18	33/64''
5/8''	18	37/64''
3/4''	16	11/16''
7/8''	14	13/16''
1''	14	15/16

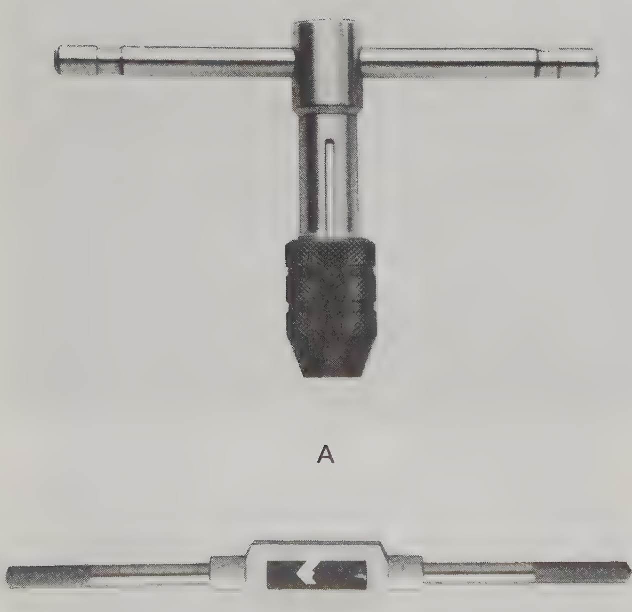
Fig. 3-7. Table of tap and drill sizes for National Fine (NF) threads.

NATIONAL PIPE THREADS		
TAP SIZE	THREADS PER INCH	DRILL SIZE
1/8"	27	11/32"
1/4"	18	7/16"
3/8"	18	19/32"
1/2"	14	23/32"
3/4"	14	15/16"
1"	11-1/2	1-5/32"
1-1/4"	11-1/2	1-1/2"
1-1/2"	11-1/2	1-23/32"
2	11-1/2	2-3/16"

Fig. 3-8. Table of tap and drill sizes for National Pipe (NP) threads.

usually turned with a special tap wrench, Fig. 3-9. Use slight downward pressure to start the cut, but release the pressure once the tap threads begin to bite. Use a lightweight oil to lubricate the cutting process. Reverse the tap every two or three turns in order to clear metal shavings from the threads. The cutting process should continue until the tap turns smoothly with little pressure.

A ***blind hole*** does not penetrate completely through a component. To thread a blind hole, use a taper tap until it touches the bottom of the hole. Then change to a plug tap. Finally, complete the thread with a bottoming tap.



A

B

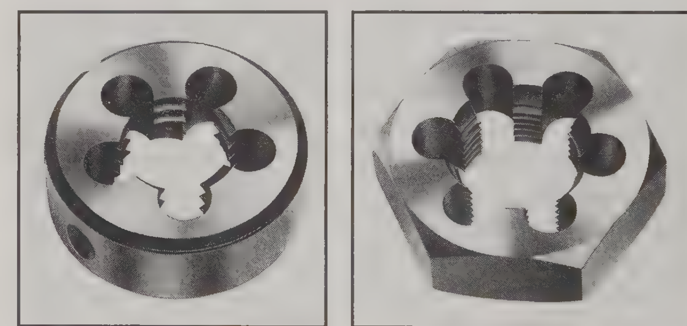
Fig. 3-9. Tap wrenches. A–T-handle tap wrench, generally used for smaller-size taps. B–Hand tap wrench provides greater leverage when using larger taps. (Triumph Twist Drill Co.)

CUTTING EXTERNAL THREADS

A *die* is a tool used to cut threads around the outside of a piece of metal, such as a bolt, rod, or pipe. A threading die may be round, square, or hexagonal in shape. See Fig. 3-10. The thread cutters may be built-in, or of the replaceable type. The leading edges of the cutters are ground away slightly to make starting easier.

Dies are available in all sizes from very small to very large, and are often sold in sets with matching taps, Fig. 3-11. The die selected depends upon the kind of thread desired (NF, NC, or NPT), and the stock diameter.

To use a die, first clamp the workpiece in a vise. Fasten the die into a die stock or holder, Fig. 3-12, and place it squarely over the end of the work. Apply downward pressure while turning the die slowly to the right until the threads bite. Use lightweight oil for the cutting process, and stop applying the downward pressure once the threads are started. The die should be backed off after each half turn to release the metal chips.



A B

Fig. 3-10. Threading dies. A–Round type. B–Hexagonal type. Square dies are also available. (Triumph Twist Drill Co.)

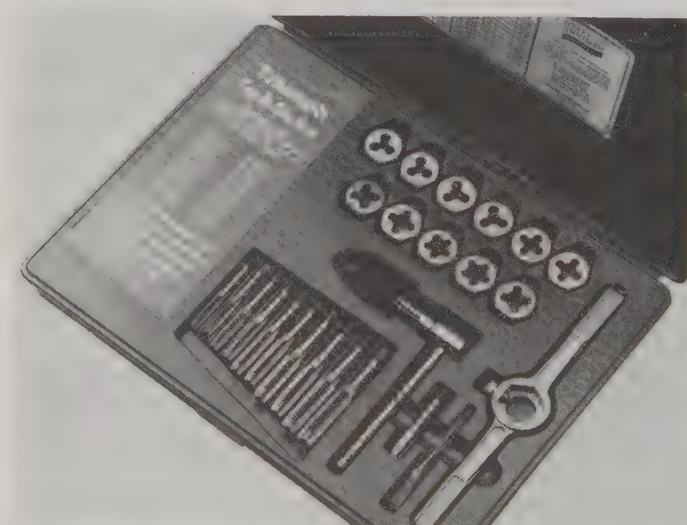
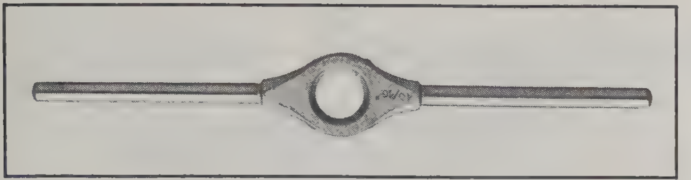


Fig. 3-11. Tap and die set. (Triumph Twist Drill Co.)



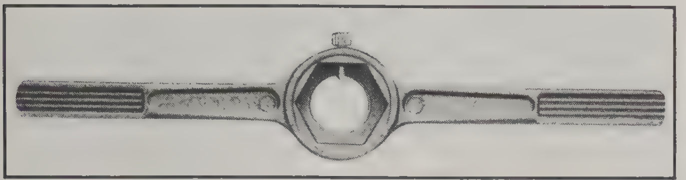


Fig. 3-12. Die stocks (holders). A–Round type. B–Hexagonal type. (Triumph Twist Drill Co.)

SCREWS

Screws are used to obtain good holding power and provide a means for repeatedly removing fastened parts. Screws are selected according to the job to be done and the material involved. Some screws are intended for use in wood, others on thin metals, and still others on thick metals. Different types of threads are used to obtain the desired holding power.

It is often necessary to drill a pilot hole before inserting a screw. This pilot hole must be smaller in diameter than the actual screw, so that the screw threads can grip the material.

SCREW SIZES

Screw sizes are measured by both length and diameter. The length is designated in inches (or fractions of an inch), but the diameter is indicated by a gauge number. Screws are available in gauges 0 (about 1/16 in.) through 24 (about 3/8 in.), and are available from 1/4 inch up to 6 inches. The most common screw gauge numbers are 2 through 16. Example: a 6 x 1 screw would be gauge number 6 in diameter and 1 inch long. The gauge number is always listed first and the length is second.

SCREW THREADS

Different types of threads are used for fastening different types of materials, Fig. 3-13. The threads used for wood screws are different from those on screws used for fastening metal. Always match the screw to the job, based on the material being fastened.

SCREW HEAD STYLES

Screws are available in many different head styles, Fig. 3-14. Screw heads are selected for holding ability and for appearance, depending upon the application.

Fig. 3-13. Different types of screw threads. (RB&W Corporation)

Head styles are often available in different types of drives. The drive determines what type of screwdriver must be used with that screw. See Fig. 3-15.

SELF-DRILLING SCREWS

Self-drilling screws are designed to drill and thread their own hole in one quick and easy step. A pilot hole is not required. See Fig. 3-16. These screws are used for

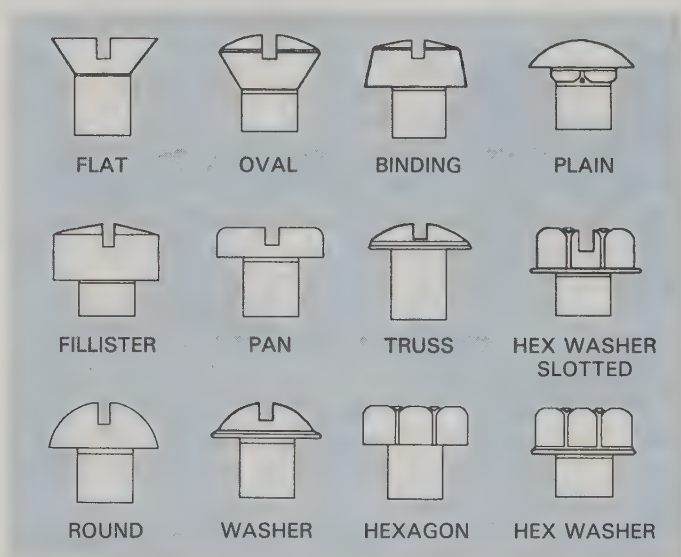


Fig. 3-14. Styles of screw heads.

Fig. 3-15. The drive type determines what screwdriver must be used.

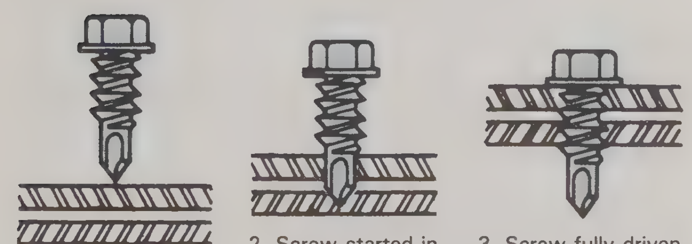


Fig. 3-16. Self-drilling sheet metal screws require no pilot hole.

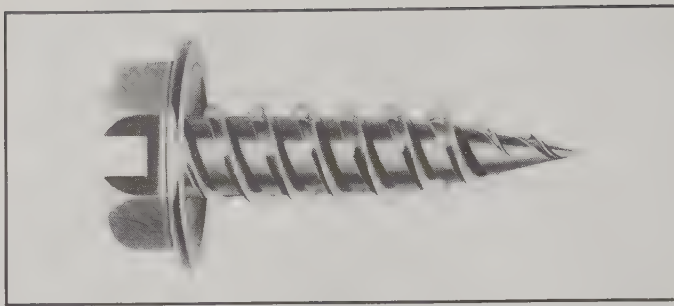
anchoring sheet metal and metal duct. These screws have hex type heads, slotted or unslotted, and are available in two different point types, Fig. 3-17.

Quick installation of self-drilling screws requires a special hex chuck driver for installing with an electric drill, Fig. 3-18. The driver head is magnetized for holding the screw while being driven. Hex chuck drivers are available in 1/4, 5/16, and 3/8 in. sizes.

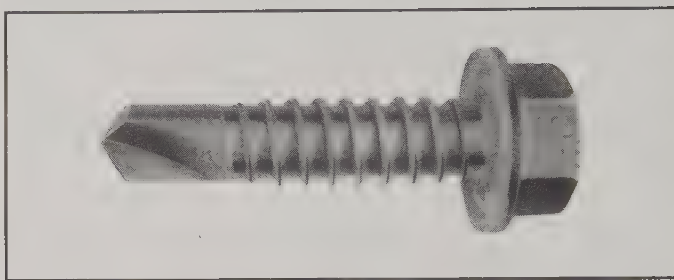
MACHINE SCREWS

Machine screws fall into a strange category all by themselves. They fill the void between a screw and a bolt. As shown in Fig. 3-19, they are actually small bolts with screw-type heads.

Machine screws are available in eleven different diameters. Eight are in numbered sizes (like screws) and three are in fractional sizes (like bolts). As the diameter

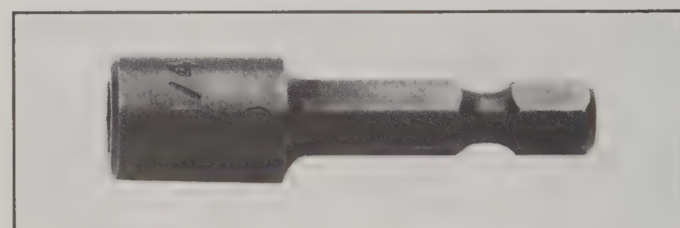


A



B

Fig. 3-17. Two different point types are available in self-drilling sheet metal screws (Malco Products, Inc.)



A

B

Fig. 3-18. Driving self-drilling screws. A–Special hex chuck driver for screws. B–Electric drill being used to drive self-drilling screws. (Malco Products, Inc.)

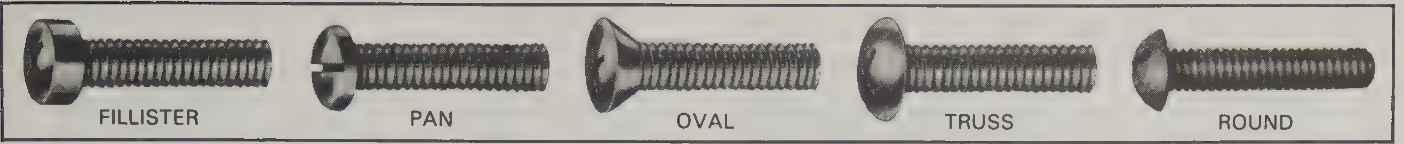


Fig. 3-19. Machine screws are available with many different types of heads. (RB&W Corporation)

gets larger, the numbers get bigger. Machine screws are available in a variety of thread forms, head shapes, and drives. Fig. 3-20 is a table of common machine screw sizes and threads.

A machine screw is designated first by its diameter number, second by the threads per inch, and finally by its length. For example: 1/4-20 x 1 indicates a machine screw that is 1/4 in. in diameter, has 20 threads per inch (NC), and is 1 in. long. To fit this screw, a 1/4-20 machine nut would be required. See Fig. 3-21.

BOLTS

A ***bolt*** is generally defined as a fastener that is used with a nut and is tightened by turning the nut. Bolts are normally used for fastening heavy metal parts together.

MACHINE SCREW SIZES AND THREADS			
MACHINE SCREW NUMBER	DIAMETER (IN.)	THREADS PER INCH	
		NATIONAL FINE	NATIONAL COARSE
2	.086	64	56
3	.099	56	48
4	.112	48	40
5	.125	44	40
6	.138	40	32
8	.164	36	32
10	.190	32	24
12	.216	28	24
1/4	.250	28	20
5/16	.3125	24	18
3/8	.375	24	16

Fig. 3-20. Table of common machine screw sizes and threads.

Fig. 3-21. To mate properly, a machine screw and nut must have the same diameter and number of threads per inch. In larger sizes, machine screws are often referred to as stove bolts. (RB&W Corporation)

Fig. 3-22 shows a variety of bolts. Bolts are made in both square and hex head forms and have either square or hex nuts.

Machine bolts (and threaded rod) are available in all common thread forms, with coarse threads being the more common. Bolt sizes are given in the same way as machine screws: diameter first, then number of threads per inch, and then the length. For example: 1/2-13 x 3 indicates a bolt 1/2 in. in diameter, 13 threads per inch (NC), and 3 inches long.

Bolt sizes ordinarily range from 1/4-20 to 1/2-13, and their lengths from 3/8 in. to 6 in. Much larger sizes are available, but are not stocked by most hardware stores.

CARRIAGE BOLTS

Carriage bolts are usually used to anchor wood to metal. The head of the carriage bolt includes a countersunk square head in addition to the roundhead. This square shoulder keeps the bolt from turning when the nut is tightened. Carriage bolts are also used where the head is not accessible to a wrench.

STOVE BOLTS

Stove bolts are made with slotted round, flat, or oval heads. They were originally used in stove construction,

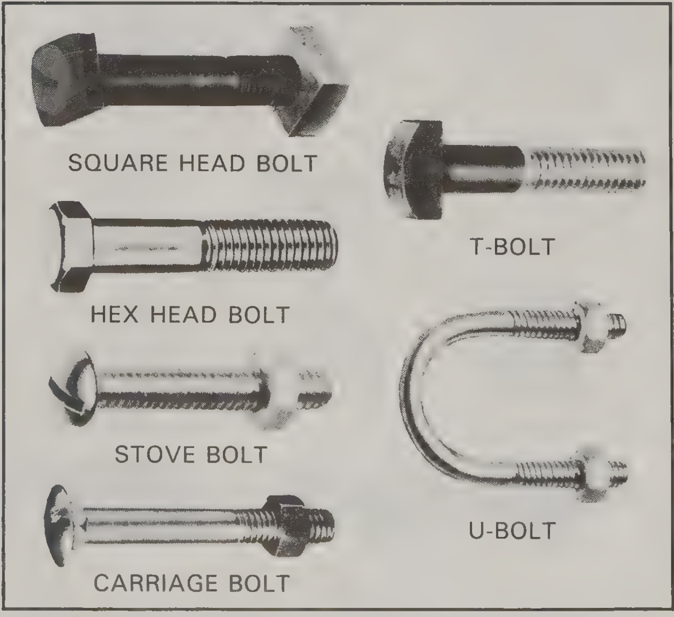


Fig. 3-22. Bolts are available in different types and use either square or hex nuts. (RB&W Corporation)

but are now sold as general utility bolts. Stove bolts are very much like machine screws, except the smallest size is 1/4 in. diameter.

NUTS

Nuts are available in a wide variety of types and sizes for use with different types of bolts and machine screws, Fig. 3-23. Different types of nuts serve specialized purposes: acorn nuts for finished appearance, wing nuts for finger tightening, slotted or castle nuts to permit locking with a cotter pin or wire. They are available in different degrees of hardness and finish.

WASHERS

Washers are used to extend the gripping area of a fastener or to prevent a nut from loosening. See Fig. 3-24. *Flat* washers are used to extend the surface area of a bolt head or nut. This prevents the bolt head or nut from being drawn into the surface of the material being fastened. *Lock* washers prevent a nut from loosening on a bolt. Lock washers are available in four styles; spring, helical, internal tooth, and external tooth.

BOLT EXTRACTORS

Occasionally, a bolt or screw may be overtightened, causing the head to break off or the fastener to snap off inside a hole. In either case, the bolt or screw must be removed and replaced with a new one. Removing a broken bolt or screw is not hard, but it is time-consuming and requires the use of a ***bolt extractor,*** Fig. 3-25.

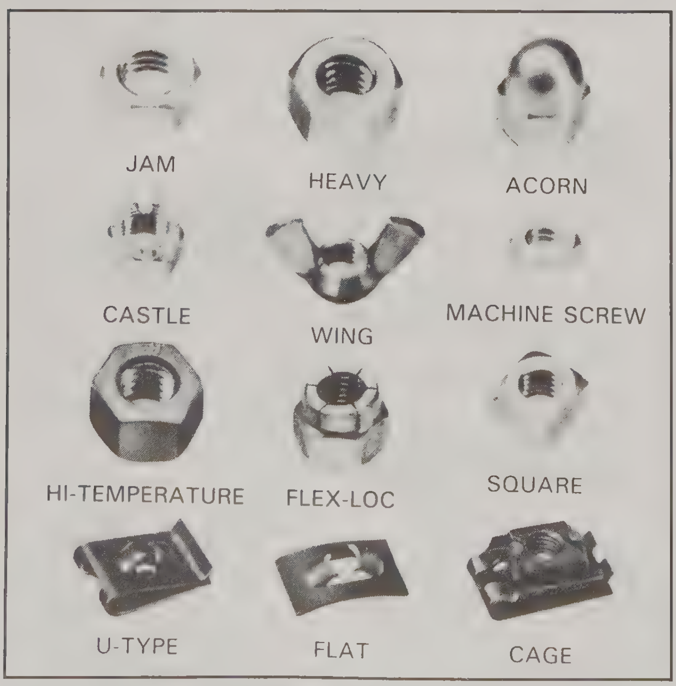


Fig. 3-23. Many types of nuts are available. (RB&W Corporation)

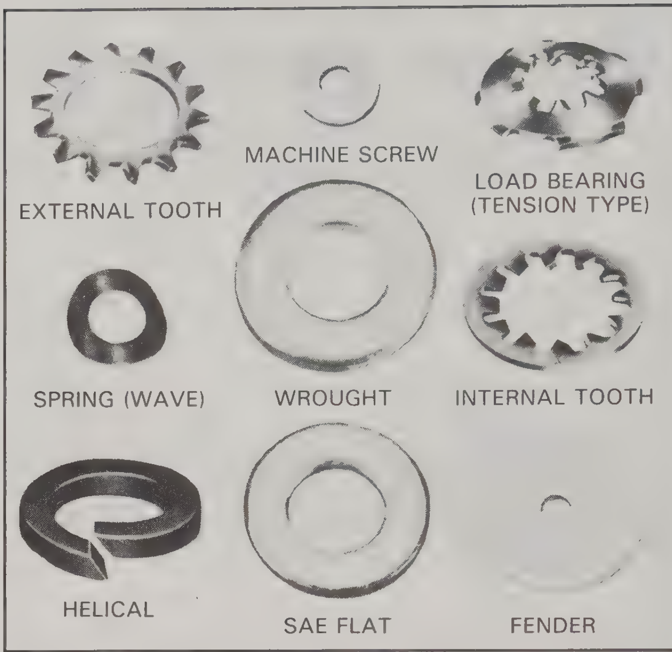


Fig. 3-24. Washers are of either the flat or lock type. (RB&W Corporation)

To remove a broken bolt or screw, you must first drill a hole in the end of the broken bolt, as shown in Fig. 3-26. Insert a bolt extractor of the proper size in the hole and use a wrench to turn the extractor counterclockwise. This causes the extractor to wedge (bite) into the hole and unscrew the bolt.

ANCHORS

There are various types of anchors used to firmly fasten materials to different kinds of surfaces. The type of anchor chosen depends upon the surface and the load (weight of object or material) that will be fastened to it. Plastic screw anchors, expanding metal fasteners,

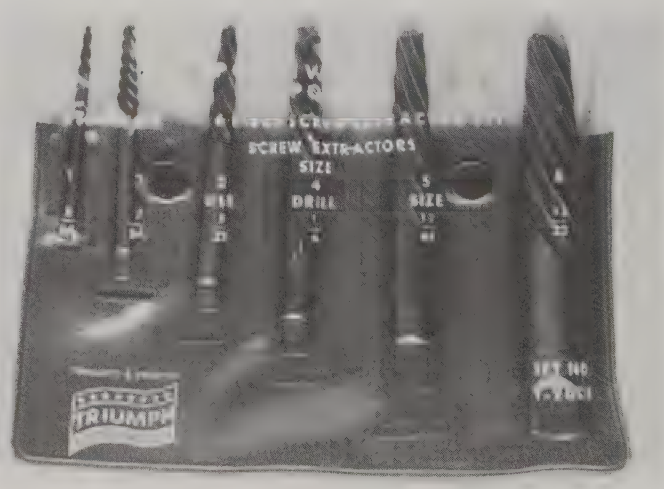


Fig. 3-25. Bolt extractors are available in sets, with sizes suited to different diameter bolts and screws. (Triumph Twist Drill Co.)

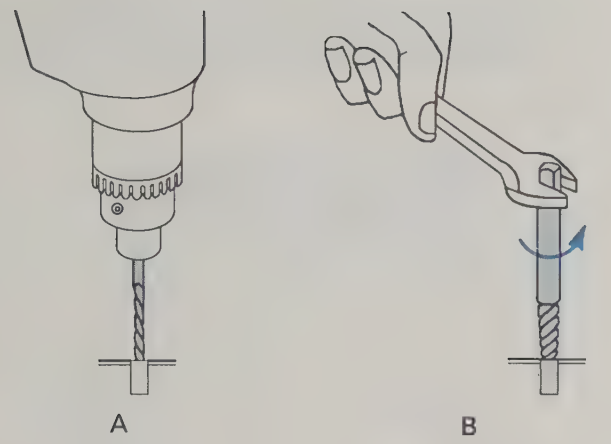


Fig. 3-26. Removing a broken bolt with a bolt extractor. A–Drilling hole in broken bolt. B–Extractor is inserted in hole and turned counterclockwise with wrench to ''back out'' broken fastener.

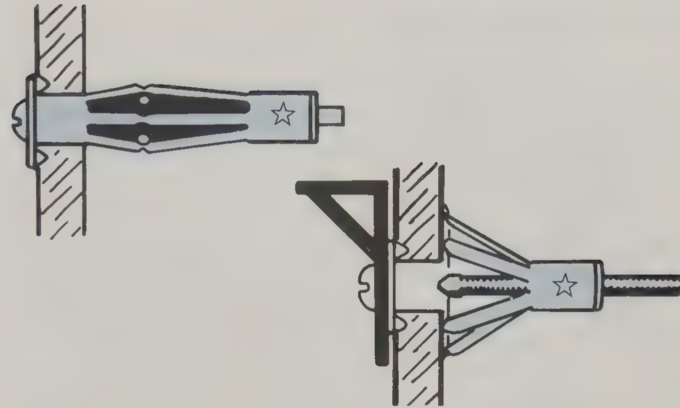


Fig. 3-28. A hollow wall anchor is inserted in a drilled hole, then expanded by tightening the screw. The legs are permanently expanded inside the hollow wall, allowing the screw to be removed and replaced as necessary. (Star Expansion Company)

and toggle bolts are used for solid or hollow walls; masonry anchors are used for solid surfaces, such as concrete or brick.

PLASTIC SCREW ANCHORS

Plastic screw anchors, Fig. 3-27, are light-duty anchors. They are used to fasten light loads to solid walls, floors, or other surfaces. As shown, the anchor is expanded against the sides of a hole by the screw, providing the friction needed to hold the load.

HOLLOW WALL ANCHORS

Special expanding metal fasteners (often called ***Molly bolts***) are used to anchor relatively light objects to hollow walls. As shown in Fig. 3-28, the fastener is inserted in a hole drilled through the wall and, as the screw is turned, the legs are pushed outward to grip the inside wall surface.

TOGGLE BOLTS

A ***toggle bolt***, Fig. 3-29, is used to fasten heavier objects to a hollow wall. A hole must be drilled in the wall that is large enough to pass the spring-loaded wings. The wings will then spread out and bear against the inside of the wall, allowing the bolt to be screwed in, Fig. 3-30.

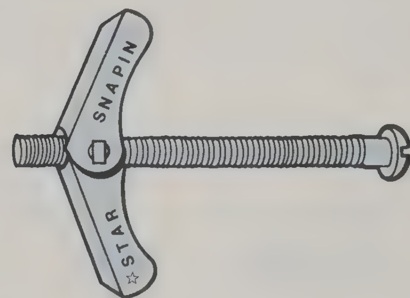


Fig. 3-29. Toggle bolt has two spring-loaded wings. It can be used to support heavier loads than other types of wall anchors.

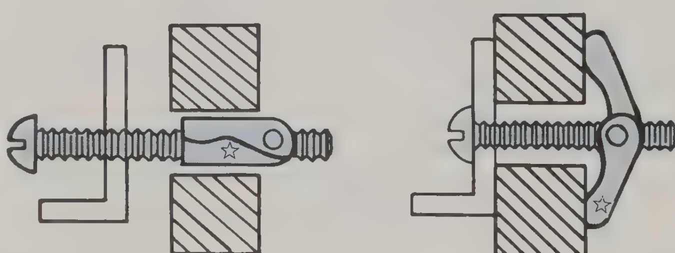


Fig. 3-30. After the toggle bolt is inserted through a hole into the hollow center of the wall, the wings are forced open by spring pressure. The wings are drawn against the inner wall surface by tightening the screw. (Star Expansion Company)

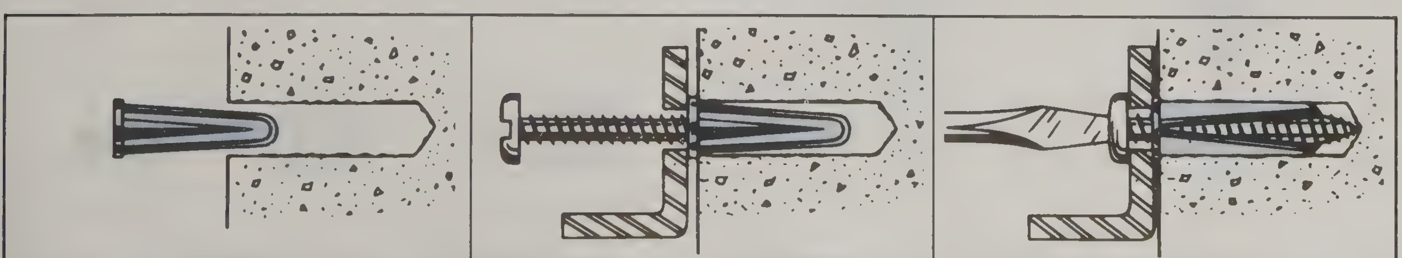


Fig. 3-27. Plastic screw anchor is inserted in drilled hole. It is expanded and wedged against sides of hole as screw is tightened. (Star Expansion Company)

MASONRY ANCHORS

Masonry anchors are available in many forms and styles. They are often used to fasten brackets to a masonry surface for such tasks as supporting lengths of conduit or copper tubing. See Fig. 3-31.

Different types of masonry anchors are used for light, medium, and heavy duty. Each type is available in different sizes for added strength and holding power.

In general, anchors are installed by drilling a hole the size of the anchor into the concrete or other material. When a bolt is inserted and tightened, the anchor expands and grips the inside of the hole, Fig. 3-32. Sometimes, a special **setting tool** is required to "set" the anchor in the hole prior to inserting the bolt. See Fig. 3-33.

OTHER FASTENERS

In addition to screws and bolts, there are a number of other types of fasteners with which you should be familiar. They are used in special situations, or to perform specific jobs.

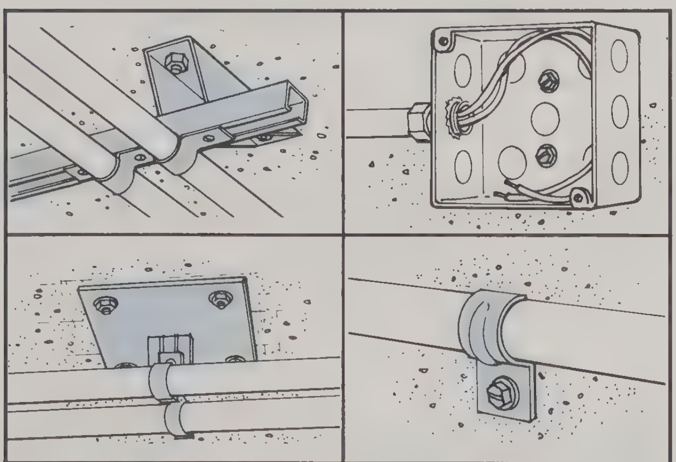


Fig. 3-31. Masonry anchors are used to fasten brackets, junction boxes, and conduit clamps to masonry walls. (ITW Ramset)

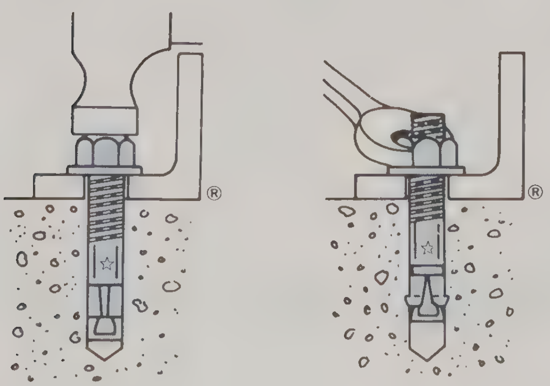


Fig. 3-32. Wedge anchors are driven into a hole drilled in masonry, then expanded by tightening the bolt. (Star Expansion Company)

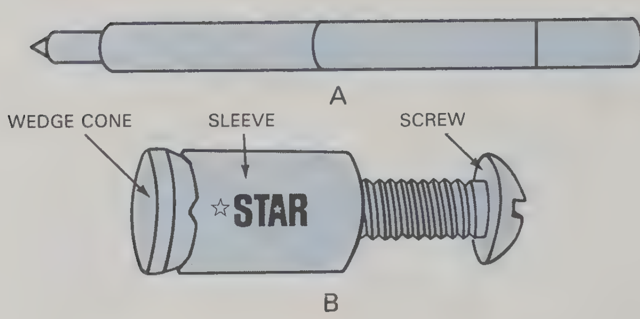


Fig. 3-33. One type of masonry anchor is set with a tool to expand a sleeve against the sides of the hole before the screw is inserted. A–Setting tool. B–Anchor, consisting of wedge cone, sleeve, and screw.

SET SCREWS

Set screws are used to anchor pulleys and fan blades to motor shafts. As shown in Fig. 3-34, set screws do not have heads because they are usually recessed inside a threaded hole. Set screws are normally driven by an Allen (hex) wrench. Set screws that *do* have heads are properly called ***cap screws.***

BLIND RIVETS

A ***blind rivet*** or **pin rivet** is used to join two pieces of sheet metal with a strong connection that will not loosen with vibration. The blind rivet, Fig. 3-35, consists of a rivet and a nail-like pin called a **mandrel**. The mandrel is designed to break off at the crimp after setting the rivet body with a hand tool, Fig. 3-36. No special skill is required to set these rivets.

Blind rivets are available in five diameters, from 3/32 in. to 1/4 in., with 1/8 in. the most popular. They are made of steel, aluminum, stainless, and copper.

THREADED ROD

Threaded rod is used in many applications because it can be cut to any length with a hacksaw. It is used to

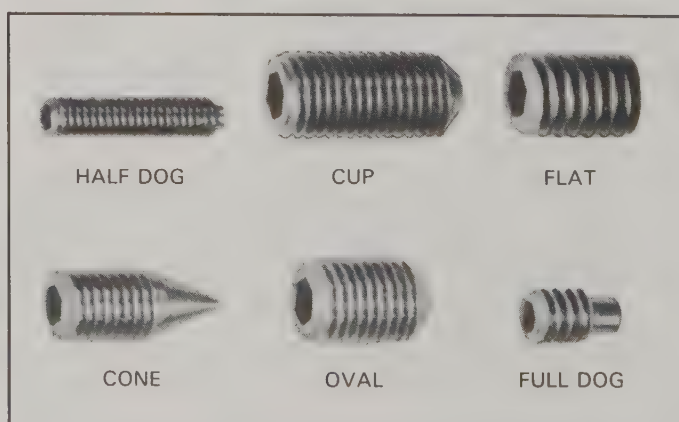


Fig. 3-34. Various types of set screws with different point styles. (RB&W Corporation)

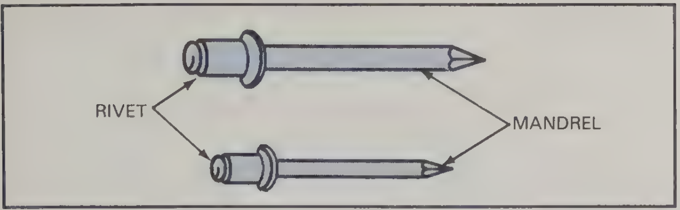


Fig. 3-35. Blind rivets are used to permanently fasten pieces of sheet metal together. The fastener consists of the rivet itself and a mandrel that is snapped off after forming a rivet head.

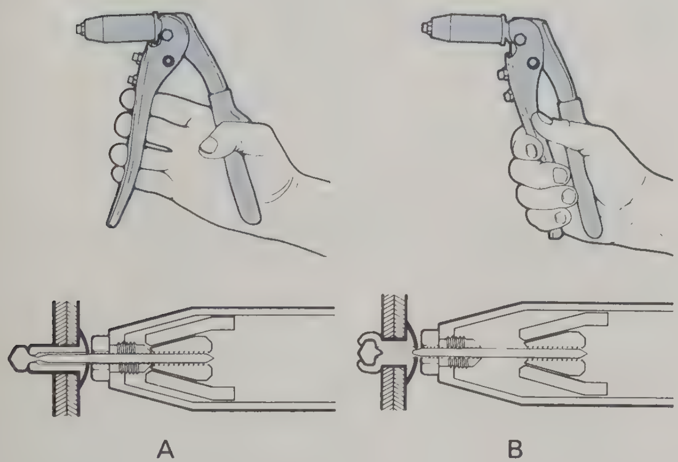


Fig. 3-36. Installation of a blind rivet. A–The mandrel of the blind rivet is gripped by the tool, and the rivet inserted through the material to be fastened. B–When the tool handles are squeezed together, the mandrel is pulled forward, deforming the rivet material to form a head. The mandrel is then snapped off, leaving the rivet in place. (Malco Products, Inc.)

make pipe hangers and is often combined with steel angle to suspend components from a ceiling. Threaded rod is available in many diameters, with coarse or fine threads.

SUMMARY

There are many manufacturers of refrigeration, heating, and air conditioning equipment, using many different types of fasteners. Working with different fasteners is an everyday task for all technicians.

Knowing how different types of fasteners are used allows quicker repair or installation. Some fasteners require the use of special tools. If you work on installation crew, you must be very familiar with all types of fasteners and methods of using them.

Since different threads are used on the same type of fasteners, failure to recognize thread differences can result in fastener damage. Damaged threads can often be repaired by using a tap or die of the proper size and type.

Service vehicles usually carry a good assortment of various fasteners, but it is sometimes necessary to purchase certain fasteners for a particular job. The technician must be aware of the different sizes and types of threads when ordering fasteners.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name two widely used thread forms.
2. Name the three common National series of threads.
3. Which series has tapered threads?
4. A tap is used to cut __________ threads.
5. A die is used to cut __________ threads.
6. Screw sizes are determined by __________ and __________.
7. True or false? Wood screws and metal screws have the same threads.
8. Machine bolts normally have __________ threads.
9. What tool is used to remove broken bolts?
10. Name three styles of lock washers.
11. Plastic screw anchors are used to fasten __________ objects to __________ walls.
12. __________ bolts and __________ bolts are used to anchor objects to hollow walls.
13. Set screws are used to anchor __________ __________ and __________ to motor shafts.
14. Threaded rod is cut to length with a __________.
15. Damaged threads can sometimes be repaired by using __________ and __________.

Copper tubing is used extensively when installing refrigeration and air conditioning systems. This outdoor condenser unit for a residential central air conditioning system has a liquid line and a suction line of copper tubing. Note the insulation on the suction line to prevent heat transfer.

Chapter 4

WORKING WITH COPPER TUBING

After studying this chapter, you will be able to:

- *Identify types and sizes of copper tubing.*
- *Select and properly use tubing tools.*
- *Describe the steps needed to make swaged connections.*
- *List the steps needed to properly make flared connections.*
- *Identify and properly use various types of copper tubing fittings.*
- *Demonstrate proper use of tube bending tools.*

NEW WORDS

ACR
annealed
chamfer
compression fittings
coupling
elbow
flare bonnet
flare cap nut
flare elbow
flare fitting
flare nut
flare plug
flare tee
flare union
flaring
flaring block
hacksaw
hard-drawn
inside diameter
lever-type tubing benders
outside diameter
oxidation
pressure drop
psi
P-trap
reamed
reducing coupling
spring benders
street elbow
swaging
sweat soldering
tee
tubing cutter
union
work-hardening
wrought fittings

COPPER TUBING

Copper tubing used for air conditioning and refrigeration is called ***ACR*** (**A**ir **C**onditioning and **R**efrigeration) tubing. It differs from copper tubing used for general plumbing work. The inside of ACR copper tubing is dehydrated to remove all moisture. The tubing is then charged (filled) with low-pressure nitrogen gas and sealed with a cap at each end.

ACR tubing is dehydrated and filled with nitrogen to keep it from being contaminated by the oxygen and moisture in the air. Oxygen atoms combine with the copper atoms (a process called ***oxidation***) to form a layer of copper oxide inside the tubing. The caps on tubing ends also help keep out moisture and dirt or other foreign matter. It is important for refrigeration systems to be free of such contaminants. Make sure to replace caps or plugs after cutting a length of tubing.

As mentioned, ACR copper differs from regular plumber's copper tubing. Plumbing copper is cheaper, but is not used in refrigeration systems because it is not protected against contamination. Also, there is a difference in size: plumbing copper is measured by its nominal ***inside diameter*** (ID), while ACR copper is measured by its ***outside diameter*** (OD). See Fig. 4-1.

TYPES OF COPPER TUBING

Copper tubing is available in ***hard-drawn*** and **soft** types. Soft copper tubing has been ***annealed*** (softened by heating it to a bright cherry red color and permitting it to cool) so that it can be bent easily. Hard-drawn copper cannot be bent easily unless it is first annealed. Both soft and hard copper are further classified according to the thickness of the tubing wall. Three thicknesses are available; K, L, and M.

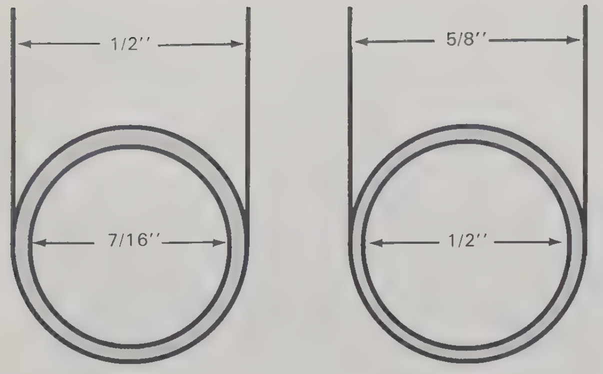


Fig. 4-1. Plumber's copper tubing and ACR copper tubing are measured differently. The ACR tubing is sized by actual outside diameter; plumber's tubing is measured by nominal inside diameter–the outside diameter usually will be 1/8 in. larger than its ID. *Pipe* is also sized by nominal inside diameter. Its OD normally will be about 1/4 in. larger, because of greater wall thickness.

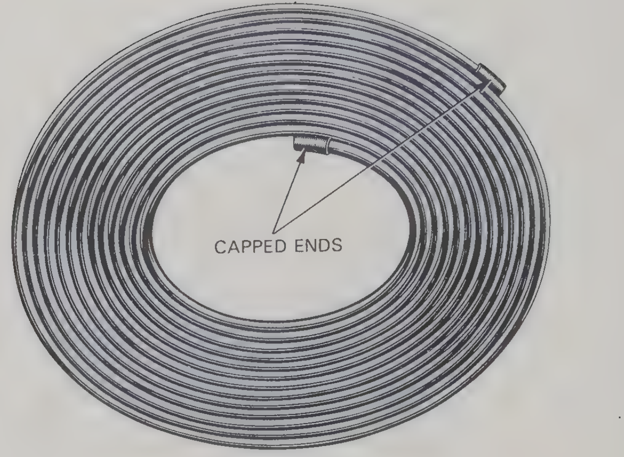


Fig. 4-2. Soft copper ACR tubing is supplied in 50-ft. coils. To prevent contamination, it is dehydrated, filled with nitrogen gas, and capped at both ends. (Mueller Brass Co.)

Type K tubing has the thickest wall. It is used in applications where abuse or corrosion might occur. Type K is usually a hard-drawn tubing and is most often used on commercial refrigeration systems.

The most common tubing is Type L, which has a medium-thick wall. It is used for residential and commercial applications. Most ACR tubing in both soft and hard types is the L thickness. When ordering ACR copper tubing, Type L is automatically provided unless another thickness is specified.

Type M is a thin-wall tubing and is *not* used on refrigeration systems because it does not meet safety code requirements. Some manufacturers use Type M copper tubing to construct water-carrying coils; plumbers may use it for small drain lines and for other noncritical applications.

Soft copper tubing

Type L soft copper tubing is available from 1/8 in. to 3/4 in. OD and is usually sold in 50-ft. coils, Fig. 4-2. As noted earlier, these coils are dehydrated and sealed at the factory.

Because soft copper is easily bent, it must be supported with clamps or brackets every 4 to 6 feet. Soft copper tubing has a tendency to harden as a result of vibration, oxidation, and bending. This is called ***work-hardening.*** Work-hardened copper will crack at stress points, especially when it is flared or formed at the tubing ends. Copper that has become work-hardened can be re-softened by heating it to a bright red surface color and then allowing it to cool.

Unrolling soft copper coils. Coils of soft copper should be handled with care because the tubing is easily damaged. Kinks, bends, flat spots, or dents will make the material unfit for use. Bending and kinking can be avoided by unrolling the coil properly. As shown in Fig. 4-3, unrolling is done by supporting the coil upright with one hand and holding the free end of the tubing stationary on a flat surface with the other hand (or a foot). The coil is then rolled in a straight line to get the desired length. Do not unroll an excessive amount, because it is difficult to re-coil the tubing without bends or kinks. After cutting off the length desired, replace the cap or plug on the end of the coil to prevent contamination.

Hard-drawn copper tubing

Hard-drawn copper tubing is hard and rigid, and is either Type L or Type K in thickness. It comes in standard 20-foot lengths that are dehydrated, charged with nitrogen, and have rubber plugs at each end, Fig. 4-4. Hard-drawn copper tubing cannot be bent easily, so soldered or brazed fittings are used when making con-

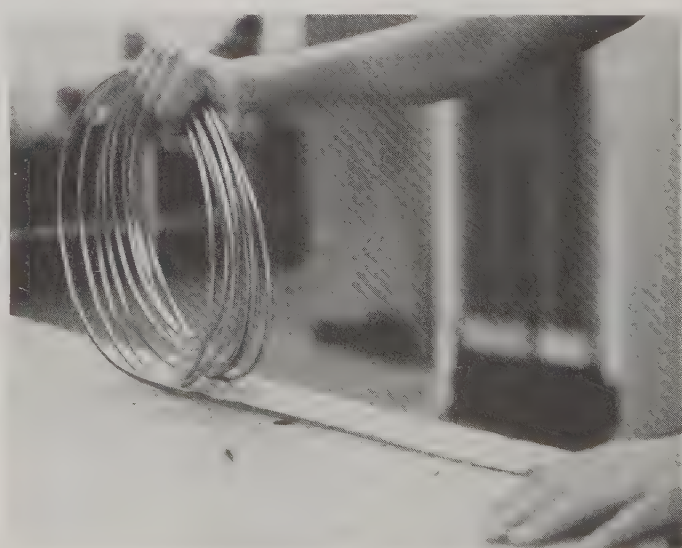


Fig. 4-3. Uncoil soft copper tubing carefully to avoid kinking. Hold one end flat on the floor or other surface and unroll as much as is needed.

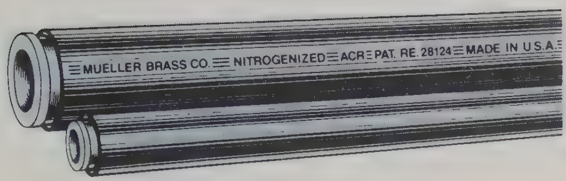


Fig. 4-4. Rubber plugs are used to seal the ends of lengths of hard-drawn copper tubing after it is dehydrated and filled with nitrogen gas. (Mueller Brass Co.)

nections or changing directions. Because of its rigidity, hard-drawn copper tubing requires fewer supports or brackets and assembly is rather quick. It is available in numerous sizes from 3/8 in. OD to over 6 in. OD.

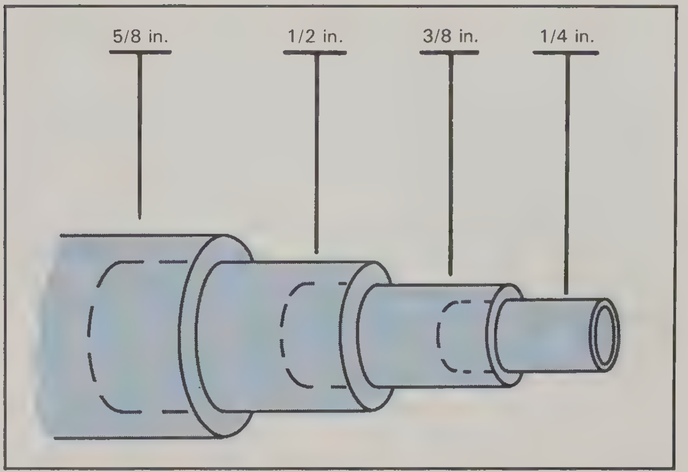


Fig. 4-5. Accurate OD sizing of ACR tubing allows different diameters to telescope inside each other.

TUBING VS. PIPE

In the early days of refrigeration and air conditioning, plumbers performed the installation and service work. These early systems used ammonia and other such chemicals as refrigerants and required the use of iron and steel pipe. Due to chemical reaction, copper tubing and fittings could not be used with ammonia and other corrosive chemicals. The development of newer refrigerants has made possible the almost universal use of copper tubing in refrigeration and air conditioning work.

The distinction between tubing and pipe is primarily wall thickness, and as a result, the joining methods used. Tubing is considered to be a *thin-walled* material (regardless of whether it is Type K, L, or M), when compared to steel and plastic pipe. The term "tubing" is generally applied to materials, such as copper or aluminum, that are joined together by means other than threads. Pipe is the term used to describe *thick-walled* materials, such as steel or plastic. Threads are cut into the pipe wall, allowing lengths of pipe to be joined together with threaded fittings that screw into place.

Telescoping can be performed with ACR tubing due to the OD sizing system and the wall thickness. As shown in Fig. 4-5, ACR 1/4 in. copper tubing will fit snugly inside 3/8 in. copper tubing, 3/8 in. will fit snugly inside 1/2 in., and 1/2 in. will fit snugly inside 5/8 in., etc. Telescoping is sometimes used to perform emergency repairs when the proper fitting is not available.

WORKING WITH COPPER TUBING

The ability to properly perform such operations as cutting, bending, and joining copper tubing is a basic requirement for success as an HVAC technician. Careful attention to correct use of tools and the development of good work habits will result in trouble-free installations and satisfied customers.

CUTTING TUBING

Cutting copper tubing is quite a simple task, but it must be performed properly. Care must be exercised not to damage the ends being cut. The most common and most accurate way to cut copper tubing is to use a ***tubing cutter,*** Fig. 4-6.

Tubing cutters make an accurate 90° cut on either hard or soft copper tubing. They are available in several sizes for use on different tubing size ranges, or in special situations. See Fig. 4-7. The tubing is positioned on the

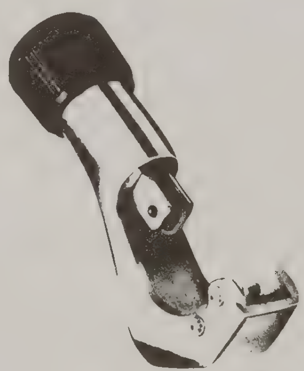


Fig. 4-6. Tubing cutters produce an accurate, clean 90° cut, resulting in strong and well-made joints. (Imperial Eastman)

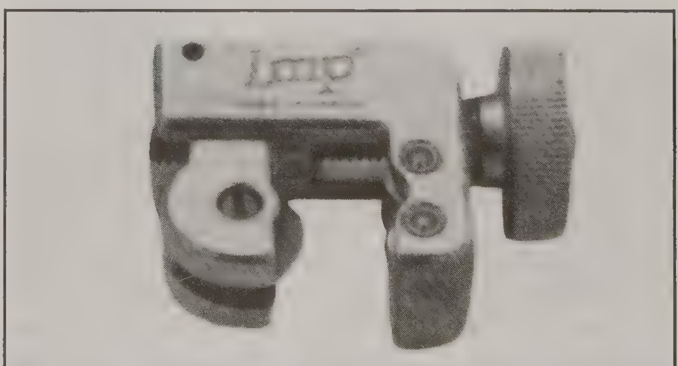


Fig. 4-7. Tiny special-purpose tubing cutter can be used to cut tubing up to 5/8 in. OD in situations where as little as 1 1/4 in. clearance is available. (Imperial Eastman)

cutter rollers with the cutter blade accurately located at the cut point. Rotation of the cutter knob raises or lowers the cutter blade. The blade is pressed firmly against the metal and the tool is rotated around the copper tubing. After each rotation, the knob is tightened to force the blade lower into the cut. Several rotations are needed to properly complete the cut.

Avoid excessive blade pressure, which will flatten the tubing and may cause a severe burr on the inside of the tubing ends. See Fig. 4-8. Keep the cutter blade sharp–a dull blade will not cut a single clean groove. Instead, it will "track", making rows of shallow cuts on the outside of the tubing. The tubing cutter should only be used on copper or aluminum tubing. Using the cutter on steel tubing or electrical conduit will quickly dull the cutter blade, making a replacement necessary.

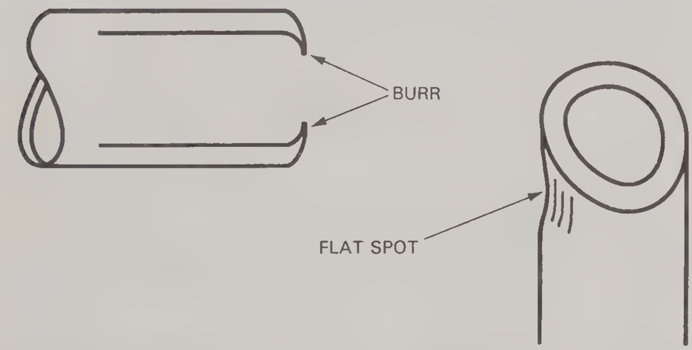


Fig. 4-8. Excessive pressure from the tubing cutter blade will cause severe burrs and can result in flat spots on the tubing.

A ***hacksaw*** is the second (and less desirable) method of cutting copper tubing. This method has two main disadvantages: it is difficult to obtain a precise 90° cut, and the sawing process creates tiny metal chips that can contaminate the inside of the tubing. To obtain the smoothest possible cut, use a saw blade with at least 32 teeth per inch. Be very careful to remove all metal chips from the tubing.

Reaming and deburring

After cutting, the tube ends must be ***reamed*** to remove burrs, and scraped to a flat surface. See Fig. 4-9. This procedure is usually performed with a pointed reamer blade built into the tubing cutter, but some technicians prefer using a pocketknife blade. Exercise care to prevent copper chips or burrs from entering the tubing. Hold the tubing upside down or at an angle during the reaming process so the chips will fall to the floor.

Proper dressing of the cut tubing end is important for several reasons. Burrs or ridges on the inside of the hole will cause problems in assembly. So will thin or uneven edges, Fig. 4-10. Thickness of the tubing *at the cut* should match the thickness of the rest of the tubing. The small amount of time and effort required to dress the cut will prove worthwhile.

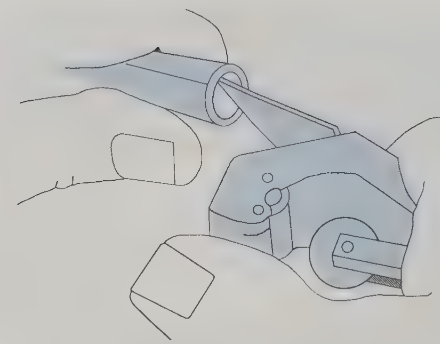


Fig. 4-9. Holding tubing with the open end downward while reaming will prevent contamination of the tubing with metal chips from the burrs.

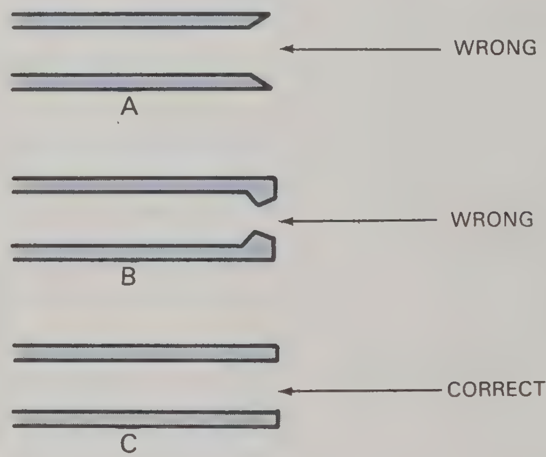


Fig. 4-10. Proper reaming of tubing. A–Tubing is excessively reamed, with too-thin wall. B–Tubing is not reamed sufficiently, so wall is too thick. C–Tubing is correctly reamed, with proper wall thickness at cut end.

BENDING COPPER TUBING

There are several types of tubing benders available to make accurate bends in tubing without causing flats, kinks, or dents. Flats and kinks are eliminated, not for the sake of appearance, but because they would restrict flow of liquid or gas through the tubing.

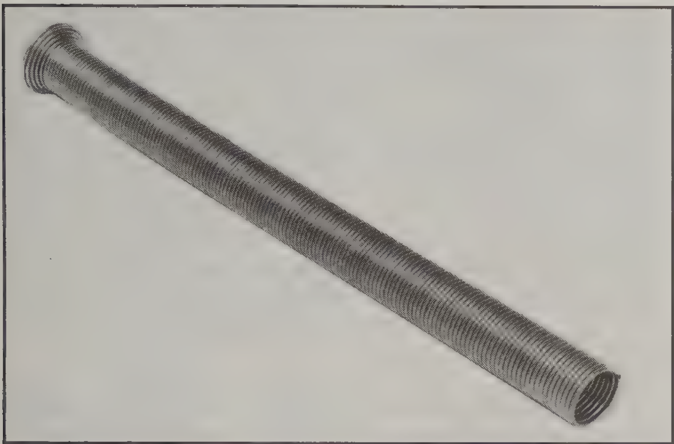
In a refrigeration system, the tubing must carry liquid or vapor from one component to another. The tubing has been carefully sized to carry a specific flow, so the technician must be careful not to create unplanned restrictions such as flats and kinks. Restrictions to flow reduce system efficiency, resulting in ***pressure drop.*** Pressure drop must be kept to a minimum.

Hand bending

Soft copper of greater than 1/4 in. diameter can sometimes be bent successfully by hand. (Smaller tubing is easily bent by hand without kinks or flats, unless the bend is very sharp.) Bending is done carefully, a little at a time, to avoid developing severe flats or kinks that must be removed. Hand bending requires skill and should be done only by experienced technicians.

Spring benders

Spring benders, Fig. 4-11, provide an efficient, low-cost method to bend soft copper tubing. They are available in a variety of sizes to fit tubing from 1/4 in. OD to 3/4 in. OD. These springs are designed to be slipped over the tubing to completely cover the area of the bend. After each bend is made, the spring is slid along the tubing to the next section to be bent.



A

B

Fig. 4-11. Spring benders are used with soft copper tubing. A–Used mostly with smaller-diameter tubing, spring benders like this one are available in a number of sizes. (Malco Products, Inc.) B–Using a bending spring on soft copper tubing is a two-handed operation.

When a bend is sharp, spring benders have a tendency to bind, or stick, to the tubing. This tendency to bind can be overcome by bending the tubing a little farther than needed, then bending it back to relieve pressure on the spring. Push, do not *pull*, on the spring to remove it from the tubing. Pulling can permanently separate the spring coils, making the bender unfit for further use. If the bend is still too tight to slide the spring off the tubing, simply twist the spring to "unscrew" it.

Very little practice is needed to accomplish proper bends in smaller tubing with a spring bender. Larger tubing, however, requires more physical force to bend, so spring benders are used on larger tubing primarily to accomplish slight bends or curves. Although the spring bender is designed for use on the *outside* of tubing, a smaller spring is sometimes inserted into the tubing to make a bend at the tubing end.

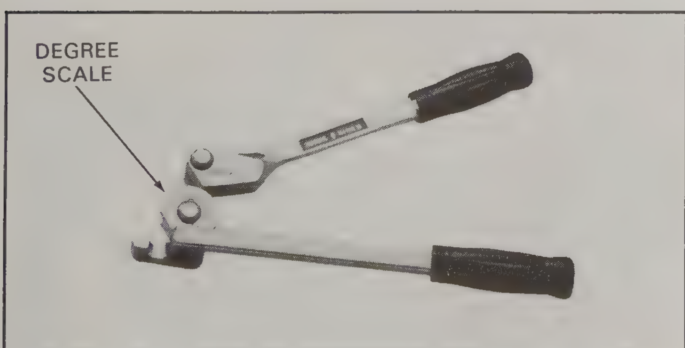
Lever-type benders

Lever-type tubing benders, Fig. 4-12, are available in a wide range of sizes. Each bender, however, is designed to fit only one size of tubing. Lever benders are easy to operate, and are calibrated to allow the making of accurate short radius bends up to 180°. They can be used on soft copper, aluminum, steel, stainless steel, and Types K and L hard copper tubing.

For the technician, making accurate bends in copper tubing is almost a daily task, especially on installation jobs. Bending has the advantages of being much faster than installing a fitting, and does not present a potential leak hazard, as fittings do. Making accurate 45° and 90° bends requires some practice; lever benders are designed to make this task easier and more accurate.

CONNECTING COPPER TUBING

The walls of copper tubing are too thin to make strong threaded connections, so other means are necessary for joining lengths of tubing together. The methods involved can be divided into two general groups



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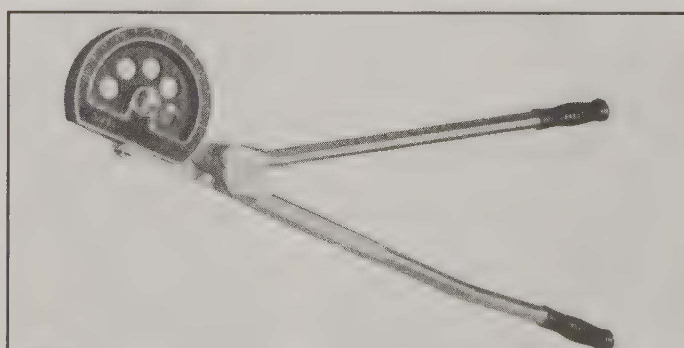


B

Fig. 4-12. Lever-type tubing benders A–Bender type used for tubing between 1/4 in. and 1/2 in. OD. A separate bender is used for each tubing diameter. Note scale used to read degrees when making bend. B–Tubing larger than 1/2 in. OD is bent with a bender of this type. Lever-type benders can make short-radius bends of up to 180° without flattening tubing. (Imperial Eastman)

that are used throughout the industry: permanent connections using soldering or brazing on swaged tubing or wrought copper fittings, and mechanical connections using threaded fittings that can be easily disconnected for making repairs or replacing defective parts. The ability to work with copper tubing and the various fittings used to make connections is a basic requirement for anyone entering the HVAC field.

SWAGING COPPER TUBING

Swaging (pronounced "swedging") is a method used to join two lengths of soft copper tubing. As shown in Fig. 4-13, swaging involves enlarging the diameter of an end of one length of tubing so that the end of the other length can be slipped into it. The connection is then soldered or brazed to make a strong leakproof joint. Performing the swaging process requires very little time, and only one brazed joint completes the connection. Swaging is often the preferred method of joining soft tubing, since the process requires little time, and only one brazed joint is needed (compared to two joints for a fitting).

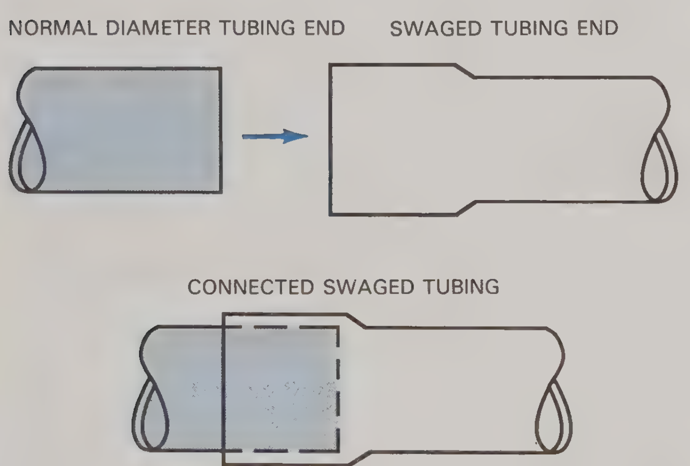


Fig. 4-13. Swaging is a process used to join tubing by enlarging the diameter of one piece so that it forms a socket for another piece. The joint is then soldered or brazed for strength and leakproofing.

Swaging methods

There are two common methods used to make swaged connections, the punch-type joint and the screw-type joint. Both punch- and screw-type joints require the use of special hand tools.

Punch-type swage. The tubing is clamped into a special tool called a ***flaring block*** with just enough tubing protruding through the block to accomplish the enlarging process. See Fig. 4-14. The depth of the finished swage should be equal to the original tubing diameter. For example, 1/4 in. tubing is swaged 1/4 in. deep, and 1/2 in. tubing is swaged 1/2 in. deep. Swaging punches are available in diameters ranging from 3/16 in. to 7/8 in.

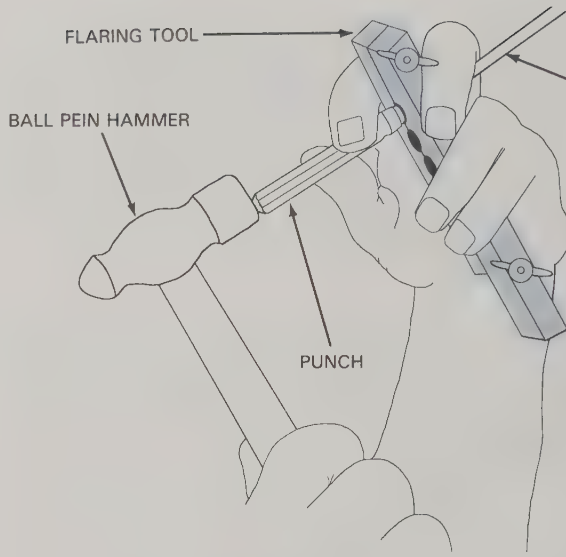


Fig. 4-14. A punch-type swaging tool uses a flaring block to hold the tubing and a hammer and punch to stretch the tubing end.

Swaging is done by clamping the tubing in a flaring block, then positioning the proper size swaging punch at the tubing end. A ball pein hammer is used to slowly drive the punch into the tubing end. The punch will enlarge the tubing end to the precise diameter required. The punch should be held firmly and straight during the swaging process. Using several easy blows is the preferred method. It permits the copper to swell slowly, resulting in a straighter and more accurate swage. (Using less force is also easier on your knuckles if you miss!) A little practice will help you quickly identify how hard to strike the punch to obtain the desired swage.

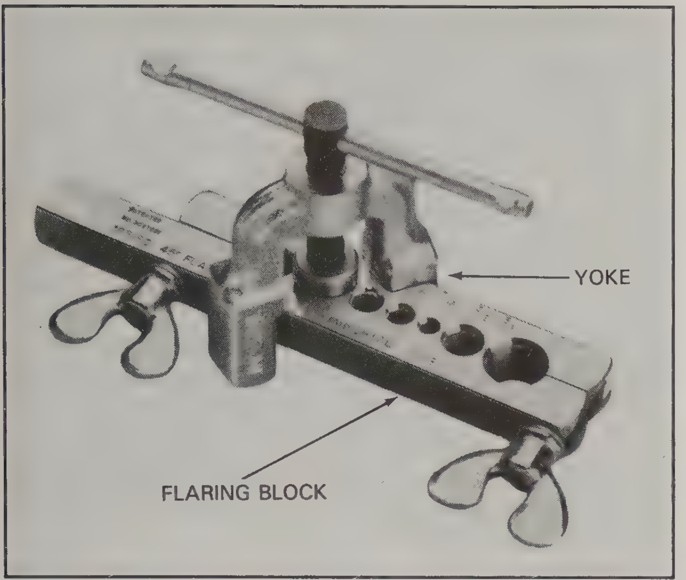
When tubing is inserted into the swage, the fit should be tight and straight. Such a fit is best for proper soldering and brazing. Loose or crooked connections are difficult to solder or braze, resulting in a weak joint. Chapter 6 is devoted to procedures for soldering and brazing tubing .

Screw-type swage. With this method, the tubing is clamped into a flaring block with the correct amount of tubing protruding. As shown in Fig. 4-15, a screw-type yoke is fitted over the tubing end and twisted to lock it onto the flaring block. By turning the handle on the yoke, the swaging adaptor is slowly forced into the tubing to stretch it. Swaging adaptors are interchangeable and range in OD from 1/8 in. to 3/4 in.

The screw-type swaging tool is often easier to use in close quarters than a punch-type tool. The screw-type tool precisely aligns the adaptor with the tubing, producing nearly perfect swages every time.

USING WROUGHT FITTINGS

Wrought fittings are sometimes called "sweat" fittings, because of the ***sweat soldering*** (or brazing) method used



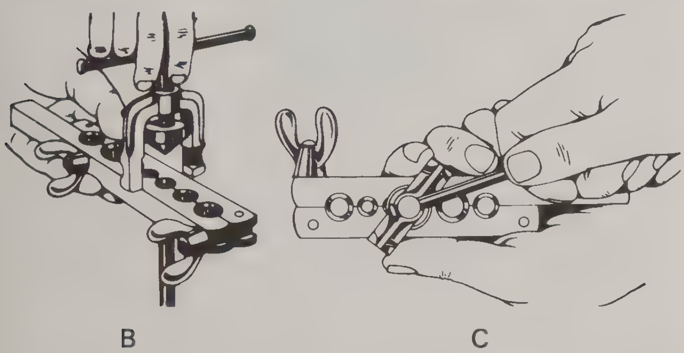


Fig. 4-15. Screw-type swaging tool. A–The screw-type tool is easier to use in close quarters than the punch-type tool. B–Self-centering yoke is slipped over flaring block. C–Yoke is rotated slightly to lock onto the block. This assures centering of the adaptor over the tubing. (Imperial Eastman)

to join them to either hard-drawn or soft copper tubing. These fittings are usually made of copper, but sometimes are brass, and do not have threads. They are sized according to the copper tubing used, and are readily available in sizes ranging from 1/4 in. to 6 in.

Wrought fittings are used where the connection is permanent, such as long runs of either soft or hard copper tubing. (They are *required* when using hard-drawn copper tubing.) The brazed connection is stronger than the actual copper tubing, but the connection *must* be brazed properly and must not leak!

Wrought fittings are designed to fit tightly over copper tubing for easy soldering or brazing. Avoid dropping or roughly handling fittings, since a dent caused by dropping can make it unfit for use.

Types of fittings

Fittings are available in many different types and sizes, so that almost any connection is possible. See Fig. 4-16 for examples of wrought fittings. The names and shapes of fittings are common to many trade areas (plumbing, electrical, HVAC, etc.), but the sizes, threads, and type of material used often differ.

Couplings. The fitting used to connect two lengths of hard copper tubing together is the ***coupling***, Fig. 4-17. Couplings are available in all sizes, and usually have openings of the same diameter on each end. A 5/8 in. coupling, for example, would be used to connect two sections of 5/8 in. hard copper tubing. These fittings also can be obtained as ***reducing couplings*** by specifying the sizes on each end. Example: "Reducing coupling, 7/8 in. x 5/8 in."

Elbows. Available in either 45° or 90° angles, ***elbows*** usually have female fittings on each end. See Fig. 4-18. Elbows are used to change direction of the tubing run.

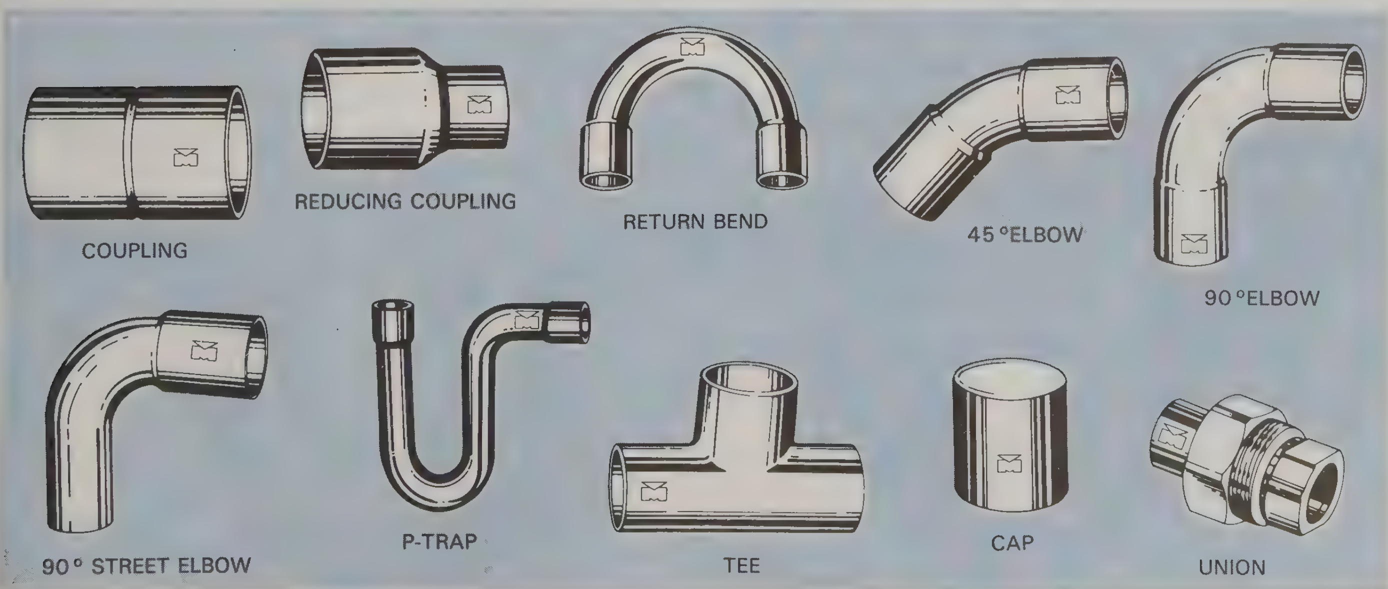


Fig. 4-16. Typical fittings used to make permanent copper tubing connections by sweat soldering or brazing. (Mueller Brass Co.)

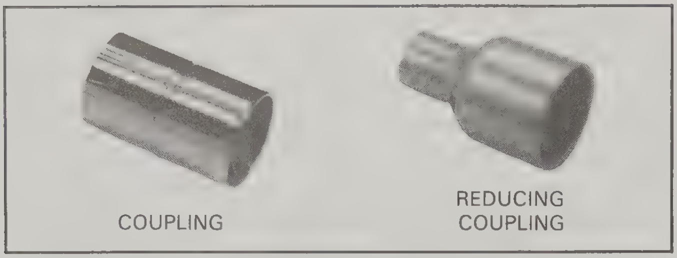


Fig. 4-17. Couplings are used to connect two pieces of tubing in a straight line. Most couplings have openings of the same diameter at both ends. A reducing coupling has openings of different sizes, allowing a larger-diameter piece of tubing to be connected to tubing with a smaller diameter. The reducing coupling shown at bottom is also a ''street'' coupling, with one end sized for the outer diameter of a larger piece of tubing and the other end for the *inner* diameter of a smaller piece of tubing. (Mueller Brass Co.)

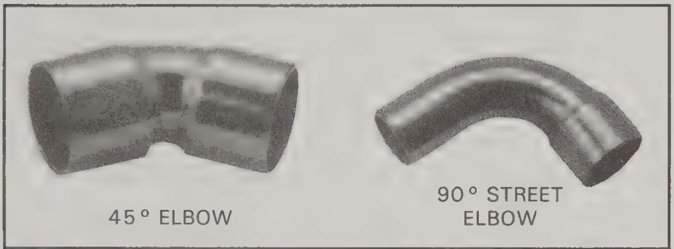


Fig. 4-18. Elbows are used to make 45° or 90° changes in direction. Standard elbows have female fittings at both ends; street elbows have a female fitting at one end and a male fitting at the other.

A “short radius” elbow makes the bend quite sharply, while a “long radius” elbow makes a more sweeping turn. The long radius type is preferred because it offers less restriction to flow of refrigerant. Like couplings, elbows are sized according to the OD of the tubing on which they are used. A 1/2 in. 90° elbow, for example, would have 1/2 in. female openings on each end to accept 1/2 in. copper tubing.

A ***street elbow*** contains a female end and a male end. Both openings are normally sized for the same size tubing. The male end of the street elbow is the same size as the tubing; the female end is sized to fit the outer diameter. They are used frequently in HVAC work to make offsets, Fig. 4-19. Street elbows reduce the number of brazed connections needed.

Tees. The fittings called ***tees*** allow you to connect a branch circuit onto an existing line of copper tubing. There is a numbering system used for tees that guarantees the correct size and type of opening in the correct place. As shown in Fig. 4-20, the straight-through connections are numbered **1** and **2**, and the branch is **3**. With this numbering system, it is possible to order a tee having different sizes at each opening. For example: “Wrought tee, 7/8 in. x 5/8 in. x 1/4 in.” (The branch would be 1/4 in. OD).

Other fittings. Wrought fittings are available to satisfy almost any need. Special fittings such as ***P-traps*** (named for the shape into which the tubing is bent), return bends, unions, and caps, can save a lot of time and trouble when installing HVAC equipment.

The ***union*** combines aspects of mechanical and permanent-type fittings. It has three parts; two shoulders and a nut for pulling the shoulders together, Fig. 4-21. The shoulders of the union are brazed to the ends of the copper tubing to be joined. The nut pulls on one shoulder while screwing onto the other shoulder, providing a mechanical connection. This results in a leakproof joint that can be disconnected as needed at the mechanical connection. This fitting is used in such applications as drain lines which may need to be disconnected for cleaning.

USING MECHANICAL CONNECTIONS

Mechanical tubing connections can be divided into two types: those made with compression fittings and and those using flare fittings. Compression-type con-

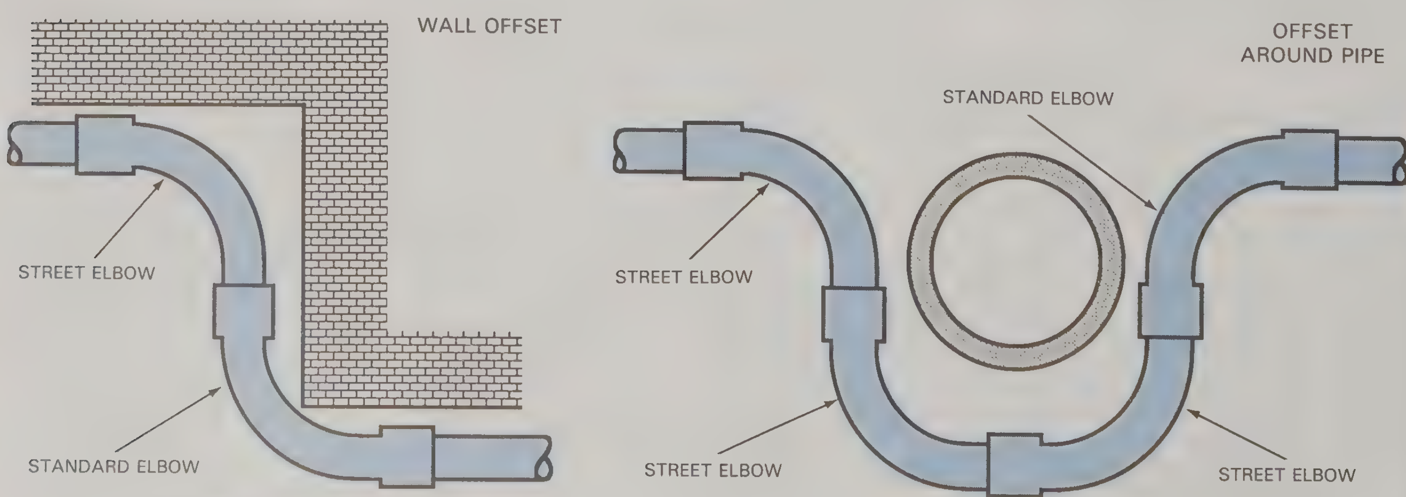


Fig. 4-19. Street elbows are used to make offsets (changes in direction that extend only a short distance) like those shown. They reduce the number of brazed connections needed.

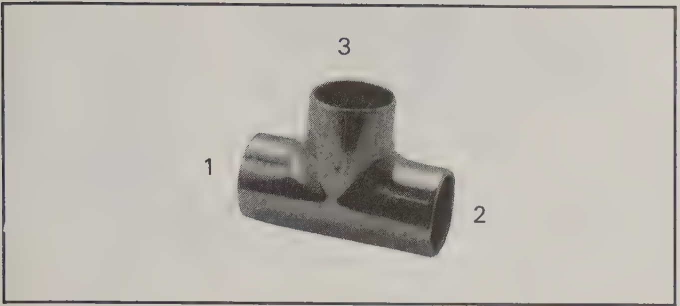


Fig. 4-20. A standard numbering system is used for the openings in a tee. The straight-through connections are numbered 1 and 2, while the branch is assigned the number 3. (Mueller Brass Co.)

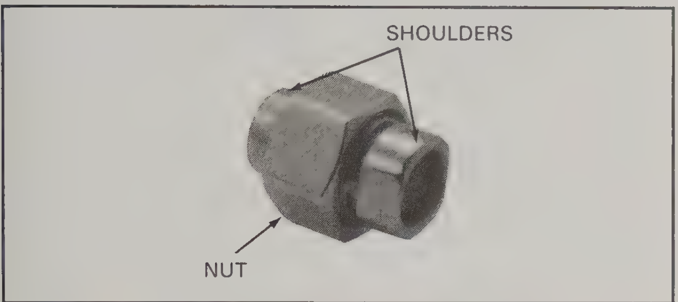


Fig. 4-21. A union combines permanent connections with a mechanical system that allows it to be disconnected. The locking nut pulls the shoulders tightly together. This makes it possible to "break" the connection when necessary for cleaning or repair work. (Mueller Brass Co.)

nections are rarely used on refrigeration systems, since they cannot withstand the high pressure and vibration associated with such systems.

Flared connections, however, are very common on all types of refrigeration systems, because they can withstand high pressure and some vibration. Failure of a flare connection can usually be traced to abuse or to lack of skill by the person who made it.

Compression-type connections

Compression fittings are commonly used in heating applications that involve only low pressure. They also are widely used for connecting gasoline, natural gas, propane, water, and air lines, where excessive pressure and vibration are not involved. Compression fittings are simple, efficient, and easy to assemble. See Fig. 4-22.

Other than making sure tubing ends are cut square and burrs are removed, no special preparation is needed when using compression fittings. Simply slip the nut and compression ring over the tubing, then insert tubing into the fitting until it rests against a shoulder. Slide the compression ring into position and tighten the nut.

Tightening the nut causes the ring to be compressed between mating surfaces, providing a leakproof connection. When the connection is disassembled, the ring will remain attached to the tubing and cannot be removed. The ring is often called a **sleeve** or **ferrule.**

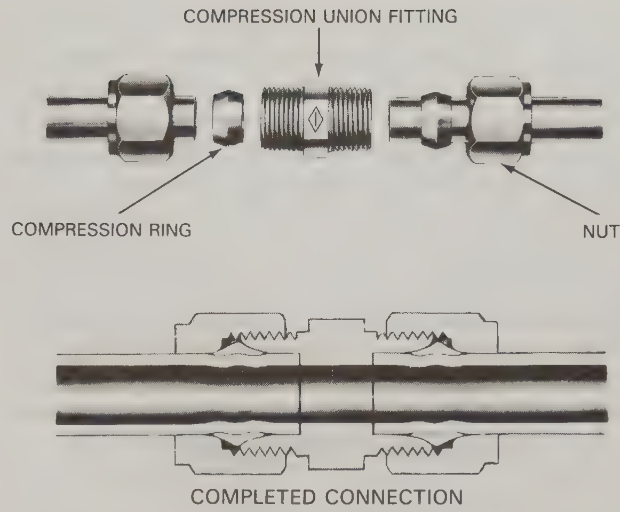


Fig. 4-22. Compression connections are made by compression (squeezing) a sleeve or ring between a fitting and a nut. Compression fittings are used more widely in refrigeration work than in air conditioning. (Imperial Eastman)

Compression fittings are *never* used on refrigeration systems, due to vibration and high pressure. However, some residential air conditioning systems use special compression fittings like the one in Fig. 4-22 to join tubing from the indoor unit to the outdoor unit. These field connections are simple, inexpensive, and quick.

Compression fittings. Fittings are sized according to the outside diameter of the tubing, ranging from 1/8 in. to 7/16 in. Nuts and compression rings needed for installation are provided with all compression fittings such as unions, elbows, and tees. Many **adaptors** are available to connect tubing with a compression fitting on one side and a flare fitting or pipe connections on the other.

Flare-type connections

Flaring copper tubing is a process of expanding or spreading the end of the tube into a funnel shape with a 45° angle, Fig. 4-23. All refrigeration *flare fittings* are made with a 45° angle, so that the tubing will fit snugly against the fitting. A flare nut is used to compress the

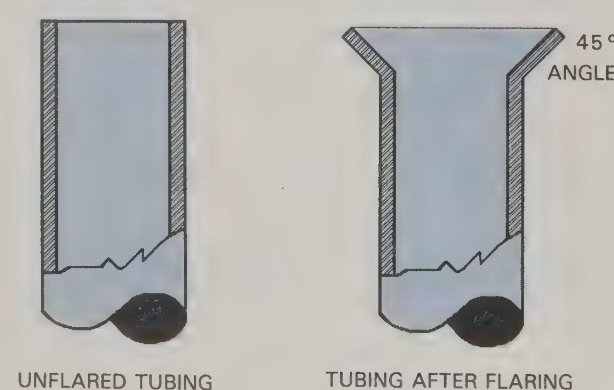


Fig. 4-23. When copper tubing is flared, the tubing end is expanded to a funnel shape. The 45° angle matches the angle used on flare fittings.

flare against the fitting to obtain a good, leakproof metal-to-metal contact. Fig. 4-24 shows a correctly made flare and several that are incorrectly made.

Refrigeration tubing connections must be leakproof to the point of withstanding at least 300 *psi* (pounds per square inch) of pressure. Because the flare connection is a mechanical, metal-to metal contact without gaskets, it is vital that proper attention and care be given to making the flares. The process is not difficult, but attention to detail is critical for leakproof connections.

The tubing end should be properly reamed before attempting to make flares. Burrs or rough edges will interfere with the smooth metal-to-metal contact, permitting leaks to occur. Making good flares requires practice.

The tubing is clamped in a flaring block with its end protruding slightly above the ***chamfer*** (beveled edge) on the block's top side. A screw-type yoke with a special flaring adaptor is then clamped onto the block and automatically centered above the tube. See Fig. 4-25. Turning the screw will force the cone-shaped adaptor into the tubing end, spreading it until it is formed to a 45° angle against the chamfer, Fig. 4-26.

Flare defects. Extending the tubing too *high* above the chamfer will result in a flare that is too wide. This prevents the nut from sliding over the flare. If tubing is too *low* in the chamfer, the result is a small flare that can pull free from the flare nut. A properly made flare will almost fill the bottom of the flare nut, without binding or rubbing the threads.

CAUTION: Overtightening the yoke screw while forming the flare will cause a thin area where the adaptor meets the chamfer of the block. This thin area weakens the flare and can cause it to break off when the nut is tightened.

Always remember to place the flare nut on the tubing *before* making the flare. (Every technician has, at one time or another, made a perfect flare and then discovered that the flare nut was not on the tubing.) To resolve the problem, you must cut off the flare, install the nut on the tubing, and make a new flare. Most tubing cutters have a special groove located on the rollers, Fig. 4-27, to permit removing only the flare.

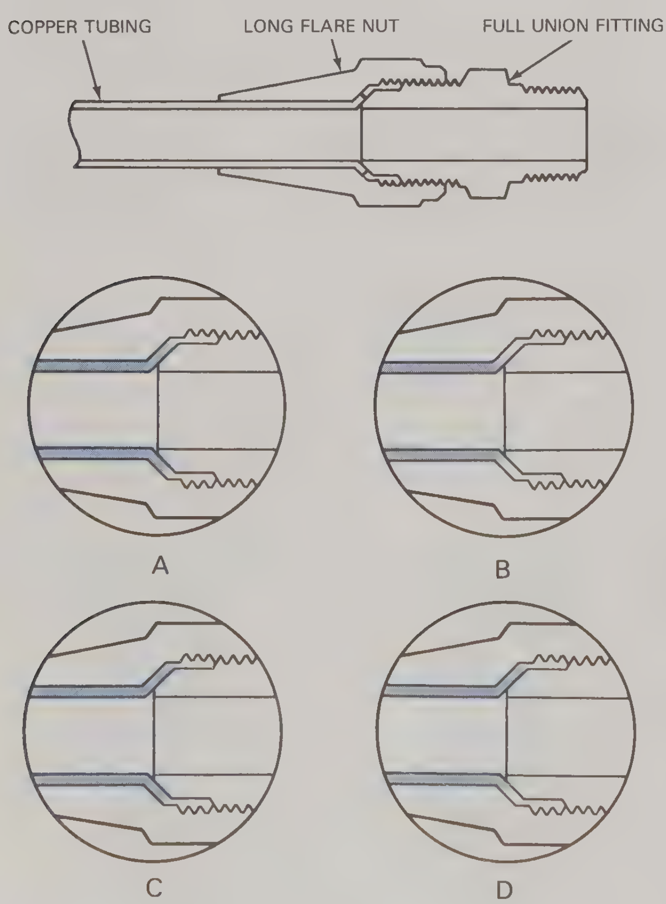


Fig. 4-24. A correctly made flare is vital to achieving a leakproof connection. A–Correctly made flare. B–Flare too small. C–Flare too large. D–Flare uneven.

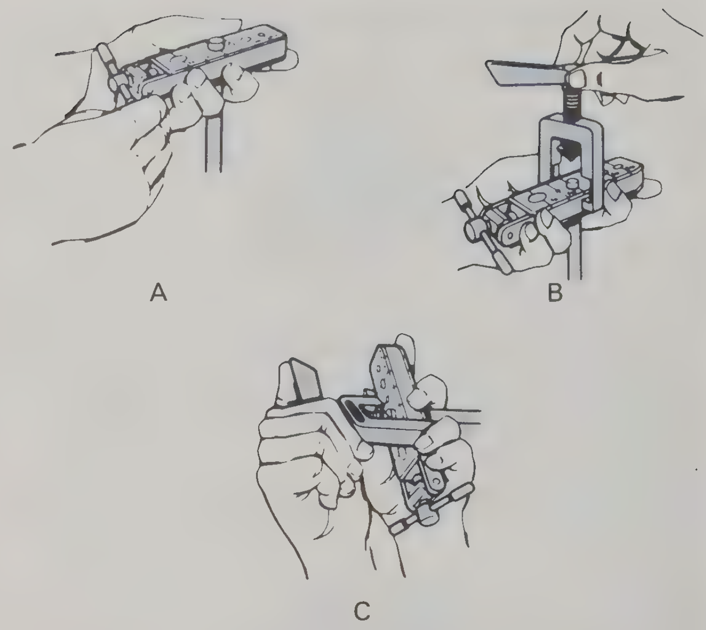


Fig. 4-25. Forming a flare. A–The tubing is clamped in the flaring block. B–The yoke is slipped over the block and twisted into place. C–The adaptor is screwed down onto the tubing to form the flare. (Imperial Eastman)

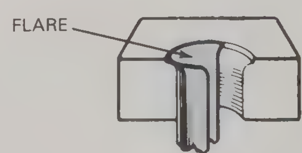


Fig. 4-26. The cone-shaped adaptor of the flaring tool stretches the end of the tubing and forces it against the chamfer, forming a 45 ° flare. (Imperial Eastman)

Flare fittings

Flare fittings are mechanical fittings intended for use on soft copper tubing. They are usually drop-forged brass and are accurately machined to form a 45° flare face (area where tubing joins the fitting). See Fig. 4-28.

Flare fittings are sized according to the copper tubing they will be used with, and are commonly available in

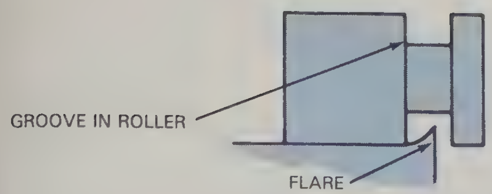


Fig. 4-27. A groove in the roller of the tubing cutter permits you to cut off just the flare, so tubing is not shortened any more than necessary. (Imperial Eastman)

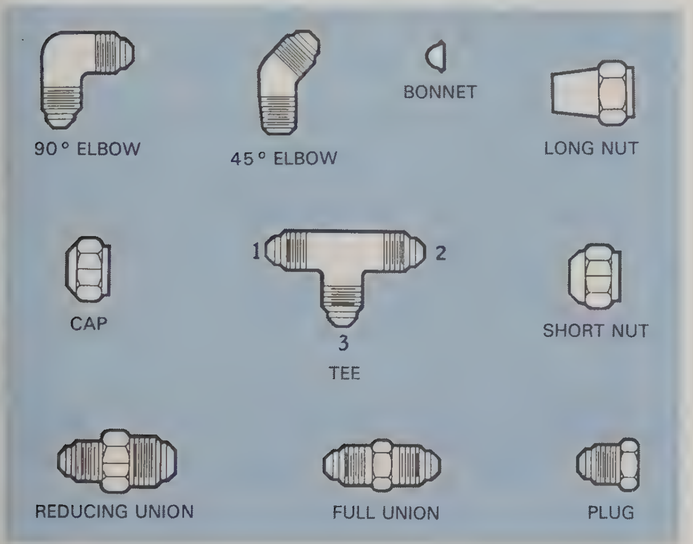


Fig. 4-28. Flare fittings are normally machined from brass. When used with a properly made flare, they provide a tight, leakproof seal for air conditioning systems and similar applications involving gases under pressure.

sizes ranging from 3/16 in. to 3/4 in. The threads for all flare fittings are SAE National Fine. This means that they cannot be connected to other threads, such as pipe threads, National Coarse, or ISO Metric.

Flare nuts. The *flare nut* is the most frequently used fitting. Flare nuts are sized by the hole through which the tubing is inserted. Since the hole just fits over the tubing, any flats or kinks in the tubing will interfere with this fit. Threads are located on the inside of the nut, and the bottom of the nut contains a perfect 45° flare to exactly match the flare on the tubing end. The tubing flare should almost fill the area at the bottom of the nut.

When the nut is screwed onto a fitting, the flare on the tubing is compressed between the nut and the fitting. To be leakproof to 300 psi, this metal-to-metal contact requires a perfect match without burrs or ridges to interfere with the seal.

Flare nuts can be obtained in either short or long style. The short flare nut is the most common. The long style is used to provide more tubing support when vibration is a factor.

Sometimes, a *reducing flare nut* is used to attach tubing to a fitting of another size. This eliminates the use of additional fittings and reduces the number of possible leaks.

Flare unions. A full *flare union* is a fitting used to connect two flare nuts of the same size. It is called a *full* union because each end of the fitting is the same size. A 3/8 in. full union would have a 3/8 in. male flare on each end. A "3/8 in. full union" is a quick way of saying: "3/8 in. MFT x 3/8 in. MFT union." (MFT = Male Flare Thread).

A reducing union performs the same function as the full union except the sizes of the flare nuts are different. It is used to reduce from one size tubing to another. For example: 1/2 in. MFT x 3/8 in. MFT. It is possible to obtain a union that has a male fitting on one end and a female fitting on the other. Such a union might be described as "3/8 in. MFT x 3/8 in. FFT." (FFT = Female Flare Thread).

Flare elbows. The *flare elbow* serves the same function as the flare union, while providing an accurate bend of either 45° or 90°. Flare elbows (often called *ells*) can be obtained in any tubing size, and can be of the conventional or reducing type. An example: "90° flare elbow, 1/4 in. MFT x 3/8 in. MFT" (or FFT).

Flare tees. The *flare tee* makes it possible to connect a branch onto an existing line of copper tubing. The numbering system for all tees guarantees the correct size and type of opening in the correct place. With the numbering system, it is possible to order a tee with openings of different sizes. For example, "Flare tee, 1/2 in. MFT x 3/8 in. MFT x 1/4 in. MFT." Position 1 is 1/2 in. MFT, position 2 is reduced to 3/8 in. MFT, and position 3 (the branch) is 1/4 in. MFT. Of course, any of the positions on the tee can be ordered with female threads.

Flare plugs. Available for all tubing sizes, the ***flare plug*** is used to seal a flare nut or similar female-threaded opening. This seal can be temporary or permanent, but is usually temporary until proper repairs can be made.

Flare cap nuts. A female nut that is used to seal off a male-threaded fitting is called a *flare cap nut*. This seal can be either permanent or temporary. The flare cap nut is used extensively on service valves and other such devices. The cap nut prevents dirt and other foreign matter from entering the system through the access fitting.

Flare bonnets. The *flare bonnet* is made of copper and is used to convert an ordinary flare nut into a cap nut. Such devices come in handy when a cap nut is not available. The bonnet is placed inside a flare nut, which can then be used to cap a male-threaded fitting.

SUMMARY

Working with ACR copper tubing is an almost everyday task. Copper tubing is used to connect system components and all connections must be durable and leakproof. This chapter has explained the various tools and procedures used for connecting copper tubing. Skill is required to perform tubing connections that will withstand vibration and remain leakproof. Poor connections result in loss of refrigerant and failure of the system to operate properly.

Most technicians can recognize tubing sizes and fittings at a glance. They do not need to measure or double-check sizes. This familiarity comes from constant use of tubing and fittings. Swages and flares are made quickly and accurately, the first time.

Beginning technicians are often assigned to tasks involving working with copper tubing and fittings. Many never progress beyond this stage. They become professional installers of copper tubing. Their pay scale is very good because such skills are important and valuable.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What gas is used to charge ACR copper tubing after it has been dehydrated?
2. The two types of ACR copper tubing are ________-________ and ________.
3. The three thicknesses of copper tubing are Type ________, Type ________, and Type ________.
   a. J, K, L.
   b. 3, 8, 12.
   c. K, L, M.
   d. A, P, W.
4. Why is ACR tubing dehydrated, filled with gas, and capped at both ends?
5. ACR tubing is sized by its ________ diameter. Plumber's copper tubing is sized by nominal ________ diameter.
6. Name two methods for cutting copper tubing. Which is preferred? Why?
7. Why is it important to remove burrs from cut ends of copper tubing?
8. Name three methods that are used to bend soft copper tubing.
9. What is the advantage of swaging over joining tubing with a fitting?
10. Hard-drawn copper tubing is connected by wrought fittings, also known as ________ fittings.
11. The openings in tee fittings are numbered 1, 2, and 3. Which one is the branch opening?
12. Name two types of mechanical connections.
13. The degree of angle on flare fittings is
    a. 30°
    b. 45°
    c. 60°
    d. 90°
14. True or false? Flare fittings are intended for use only on hard-drawn copper tubing.
15. The flare ________ is the most frequently used flare fitting.

Chapter 5

WORKING WITH PIPE

After studying this chapter, you will be able to:
- *Discuss the uses for different types of steel and plastic pipe.*
- *Identify various sizes of pipe.*
- *Recognize types of fittings and use them properly.*
- *Select pipe tools and describe their proper use.*
- *Describe how to repair leaks in piping.*
- *Give the procedures for solvent welding rigid plastic pipe.*

NEW WORDS

ABS
adaptors
close nipple
corrosion
CPVC
galvanized
jaw-type pipe wrench
malleable
nominal
pipe compound
pipe die
pipe fittings
pipe thread
pipe vise
PVC
shoulder nipple
solvent cement
solvent welding
strap-type pipe wrench
tapered

USES FOR PIPE IN HVAC

Steel pipe or plastic pipe, depending upon the application, may be required for many HVAC installation and repair jobs. Steel pipe has traditionally been used for water lines, drains, and natural gas supply lines to furnaces. However, plastic pipe is rapidly replacing steel in many applications involving water flow, drainage, and heating systems. Neither steel nor plastic pipe is used for carrying refrigerants, but may be used to connect certain accessories to the system. Such accessories include water cooling towers, water-cooled condensers, and condensate drains. Local and state building codes specify the acceptable uses of each type of pipe. The technician must develop and perfect the skills needed to work with both steel and plastic pipe.

STEEL PIPE

Steel pipe is available in unfinished (black) or ***galvanized*** (zinc-coated) forms. Galvanized pipe is usually specified for water and drain lines because it is less subject to rust than unfinished pipe. Black pipe is generally used for natural gas applications. However, local codes or installation rules will govern specific applications.

Steel pipe is available in a standard length of 21 feet. There are three grades or strengths; standard, extra strong, and double extra strong. *Standard grade* is acceptable for most plumbing applications.

MEASURING PIPE

Steel and plastic pipe are measured by the inside (flow) diameter, which is *not* precise and is called the ***nominal*** (approximate) size. As you read in Chapter 4, this method is different from that used to measure ACR copper tubing. ACR tubing is very accurately measured by outside diameter (OD). See Fig. 5-1.

The ID, or nominal size, is not precise because wall thicknesses of pipe will vary slightly. Nominal size is, however, considered acceptable for determining size for pipe and pipe fittings. *Sizes given for all plumbing pipe and fittings, as well as for plumber's copper tubing, are*

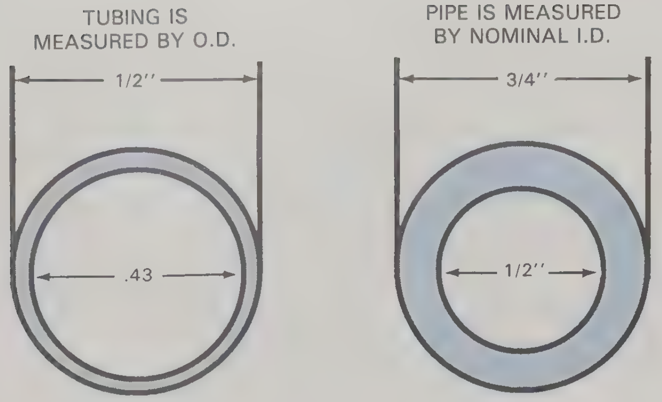


Fig. 5-1. Pipe measurements and ACR tubing measurements differ. Pipe is measured by its nominal inside diameter (ID), while ACR tubing is measured by its more precise outside diameter (OD). Note that wall thickness of pipe is much greater than that of tubing.

nominal sizes. Fig. 5-2 compares the nominal, I.D., and O.D. sizes of steel pipe.

Nominal size copper tubing is used by plumbers for water lines and drains. If a plumber asks to borrow some 1/2 in. copper tubing from you, the ACR tubing you provide would be 5/8 in., since it would have the desired ID of 1/2 in.

PIPE THREADS

The walls of pipe are quite thick (compared to the walls of tubing). This makes it possible to cut threads on the walls to connect pipe with fittings. ***Pipe thread*** is very different from other types of threads. Pipe threads are ***tapered*** (sloped) 1/16 in. for every inch of length, Fig. 5-3.

Pipe threads are specially formed, tapered V-threads made in a conical spiral (like the threads on a wood screw). The taper causes the threads to bind together and make a seal as a fitting is tightened. Approximately 1/2 in. of threads are usable before the fitting begins to tighten on the taper; the remaining threads are mostly

PIPE SIZES (INCHES)		
NOMINAL SIZE	INSIDE DIAMETER	OUTSIDE DIAMETER
1/8	0.269	0.405
1/4	0.364	0.540
3/8	0.493	0.675
1/2	0.662	0.840
3/4	0.824	1.050
1	1.049	1.315
1-1/4	1.380	1.660
1-1/2	1.610	1.900

Fig. 5-2. This table lists the nominal size, ID, and OD of steel pipe commonly used in plumbing work.

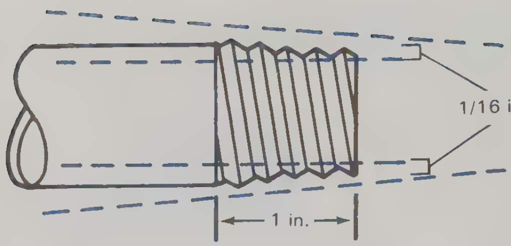


Fig. 5-3. Pipe thread slopes or tapers 1/16 in. for every inch of length. This helps form a tight seal between the fitting and the pipe.

incomplete. A special ***pipe compound*** (usually referred to by plumbers as "pipe dope") is normally brushed onto the threads before assembly to ensure a strong, leakproof seal. In some applications, Teflon® tape is used, instead of pipe dope, to form a seal.

Pipe thread differs from National Coarse (NC) threads and National Fine (NF) threads in several ways. Both NC and NF are *non-tapered* machine-type threads and are based on the outside diameter of the fastener. Pipe thread sizes are based upon the nominal size of pipe.

TOOLS USED WITH STEEL PIPE

Cutting and threading steel pipe requires the use of tools especially designed for these tasks. The tools used when working with steel pipe are described in the following paragraphs.

Pipe vise

A ***pipe vise*** is a special tool used to securely hold steel pipe in position for cutting and threading. There are two basic types, the yoke vise and the chain vise. See Fig. 5-4. Some vises mount on a bench, while others are portable and free-standing on tripod-type legs. Some vises are equipped with an electric motor to rotate the pipe in either direction for easy and fast cutting and threading.

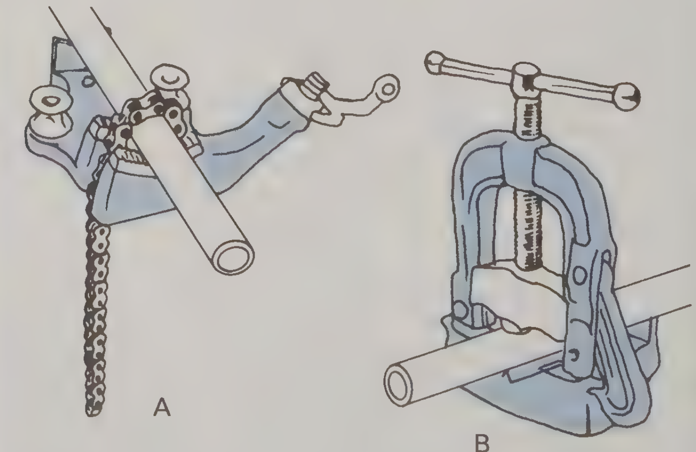


Fig. 5-4. Pipe vises. A–Bench-mounted chain vise. B–Bench-mounted yoke-type vise. (The Ridge Tool Company)

Pipe cutter

Steel pipe is cut in basically the same manner as copper tubing, using a cutter rotated around the material being cut. The pipe cutter is larger than the tool used for tubing, has a blade specially manufactured for cutting steel pipe, and is designed for heavy-duty use. See Fig. 5-5. Pipe cutters are available in different sizes, with each able to cut several different diameters of steel pipe.

Fig. 5-5. The cutter used for steel pipe is larger than the tubing cutter. There are different types available, such as this model with four cutting wheels, designed for use in tight quarters where cutter cannot be rotated completely around the pipe. (The Ridge Tool Company)

When cutting steel pipe, allow about 1/2 in. of extra pipe length at each end for threading. This is necessary because about 1/2 in. of thread will disappear into each connecting fitting. Steel pipe can also be cut with a hacksaw, but the work must be done carefully to obtain a straight cut. Regardless of the cutting method used, the cut ends must be reamed to remove the burr on the inside of the hole. This is done with a special reaming tool, Fig. 5-6, designed for use on steel pipe.

Pipe wrench

Pipe wrenches, Fig. 5-7, are designed for holding and turning steel pipe and fittings. They are available in different sizes, with capacities ranging from 3/8 in. to 8 in., and in two different types. The regular ***jaw-type pipe wrench*** is used in service where tooth marks from the wrench jaws are not objectionable. Tooth marks can be avoided by using a ***strap-type pipe wrench***.

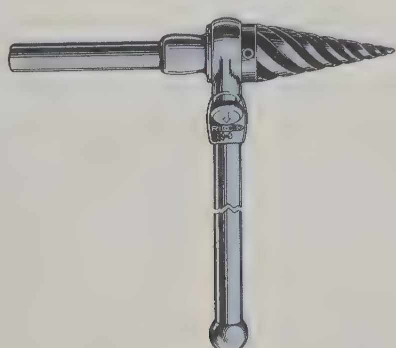


Fig. 5-6. This spiral pipe reamer will de-burr pipe in nominal sizes from 1/8 in. to 2 in. A ratchet handle permits use in tight quarters. (The Ridge Tool Company)

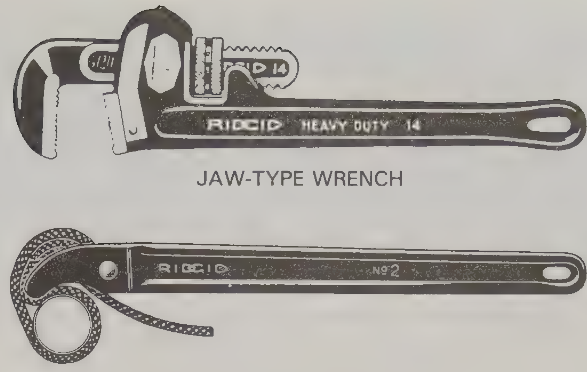


Fig. 5-7. There are two basic types of pipe wrenches. The jaw-type pipe wrench has sharp teeth to provide a firm grip on pipe and fittings. In situations where tooth marks on the pipe or fitting would be objectionable, the strap-type pipe wrench is used. (The Ridge Tool Company)

When using the jaw-type wrench, as shown in Fig. 5-8, it is important to maintain a gap between the back of the hook jaw and the pipe. This concentrates pressure at two points and produces maximum gripping action and rotating force. Always *pull*, in the correct direction on the wrench handle. This will cause the jaw teeth to bite into the pipe. Pulling in the wrong direction will cause the wrench to lose its grip and slip around the pipe. Pipe wrenches are normally used in pairs, one for holding the pipe and the other for turning the fitting.

Pipe die

The ***pipe die*** is a special tool used to cut threads on the outside of steel pipe. As shown in Fig. 5-9, the die is

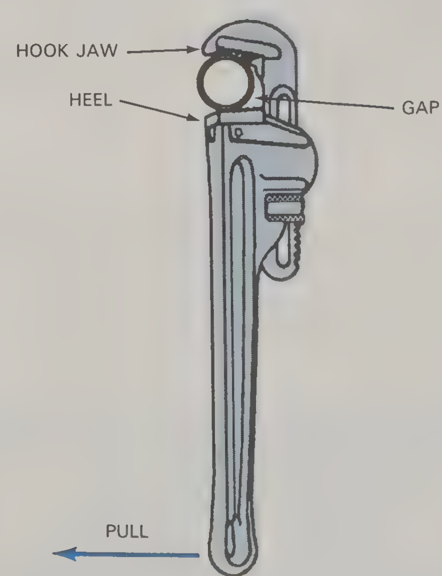


Fig. 5-8. Proper use of a jaw-type pipe wrench. By pulling in the direction shown, the teeth will grip the pipe tightly. Pulling in the opposite direction would cause the grip to loosen and allow the wrench to slip. Leaving a slight gap between the pipe and the back of the jaw will concentrate the force at two points for a better grip.

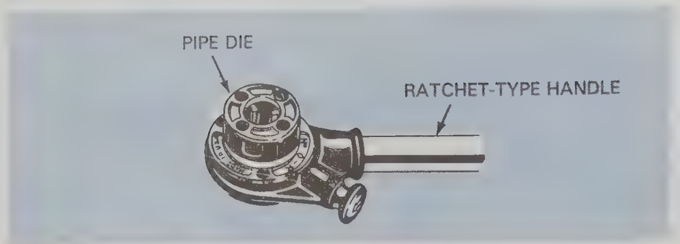


Fig. 5-9. A pipe die is used to cut threads on the outside of pipe. A different die must be used for each pipe size. The ratchet-type handle shown can be reversed to ''back off'' the die after the threads have been cut. (The Ridge Tool Company)

an individual tool that fits into a special handle used to turn the die on the end of the pipe. Each die is accurately sized to fit a particular size of steel pipe. When changing pipe size, the die must also be changed. The ratchet-type handle shown is reversible, so that the die can be unscrewed from the end of the pipe once the threads are cut. A special **thread cutting oil** is used to keep the die from getting too hot and damaging the cutting edges.

PIPE FITTINGS

Pipe fittings are made of annealed (softened by heating) cast iron. Annealed cast iron fittings are called ***malleable*** fittings. They can withstand more bending, pounding, and internal pressure than ordinary cast iron.

Pipe fittings are very similar to those described in the chapter on copper tubing. The major difference is that the pipe fittings are threaded, rather than smooth like sweat-soldered tubing fittings. Also, pipe fittings are always sized according to the nominal size (ID) of the pipe being used. This can be confusing when accustomed to dealing with ACR tubing that is sized by OD, but a little practice and comparing of sizes will quickly eliminate confusion.

Elbows

Pipe elbows, or "ells" are necessary when changing direction of a piping run. They are readily available in all sizes and in 90° or 45° types, Fig. 5-10. These are also available as "street ells," which means that one end of the elbow is female while the other end is male.

Fig. 5-10. Elbows are available in all nominal pipe sizes, and in either 90° (as shown) or 45° types. The street elbow has female threads on one end and male threads on the other.

Couplings

A coupling is a short fitting with female threads at each end, used for connecting two lengths of pipe in a straight line. See Fig. 5-11. Reducing couplings are used to connect two different *sizes* of pipe in a straight line.

Tees

Tees are used to create a branch from an existing line of pipe, Fig. 5-12. Pipe tees have numbered openings just like those used on copper tubing. #1 and #2 is straight through, while the branch is #3. Pipe tees can be obtained in almost any combination of sizes, all with female threaded openings. A 1/2″ tee would have the same size (1/2″) at all three openings. Each size for a **reducing tee** must be given according to the numbering system. For example, 1/2″ x 3/4″ x 1/4″. The branch would be 1/4″.

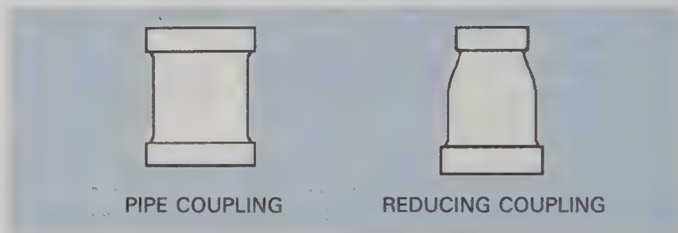


Fig. 5-11. Couplings connect pipe lengths in a straight line. The reducing coupling allows different-sized pipes to be connected.

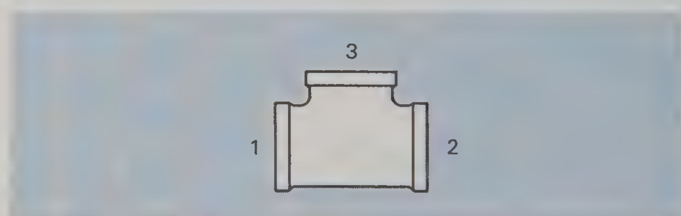


Fig. 5-12. Tees permit the connection of a branch to a main pipe. Numbering of the openings in a tee follow a universal system: openings 1 and 2 are the main line; 3 is the branch line opening.

Reducing bushing

A **reducing bushing** has male threads on the outside and female threads inside. See Fig. 5-13. It is used to reduce the size of a female opening. For example, a water valve with 3/4 in. female openings can be used on 1/2 in. pipe by installing reducing bushings (3/4 in. x 1/2 in.) in each side of the valve. Reducing bushings are available in a wide variety of sizes.

Caps and plugs

Caps and plugs are used to seal openings. Caps have female threads and are used to close the end of a pipe. Plugs have male threads and are used to close openings in fittings. All nominal sizes are readily available.

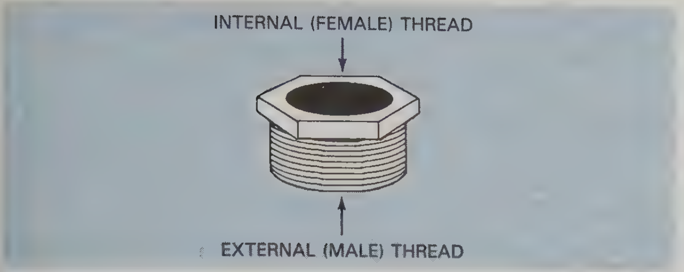


Fig. 5-13. A reducing bushing threads into a female opening (such as one end of an elbow) to allow a smaller pipe to be connected easily.

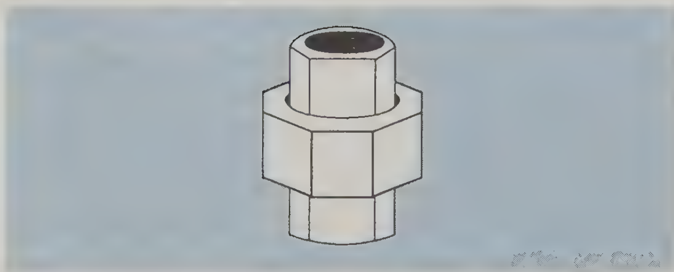


Fig. 5-15. Since all pipe threads are right-handed, a run of pipe cannot be completed unless a union is installed. The union also allows pipes to be disconnected for repairs.

Nipples

Nipples, Fig. 5-14, are short lengths of pipe that are threaded on each end and used to connect fittings that are located close together. Nipples can be purchased in any pipe size, in lengths up to 12 in. Length is determined from end to end, including threads.

A very short nipple is called an **all-thread** or ***close nipple*** because it is threaded along its entire length. A ***shoulder nipple*** has a short section of unthreaded pipe. These nipples are very convenient when making short connections.

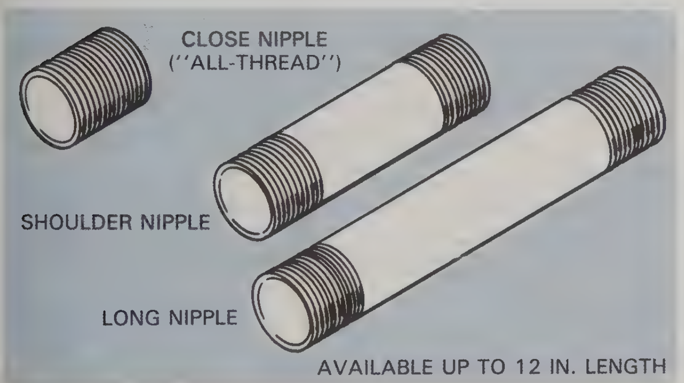


Fig. 5-14. Pipe nipples are short pieces threaded at both ends. They are useful in connecting fittings that occur close together.

Unions

A **union**, Fig. 5-15, is a special fitting required to complete a run of pipe. Pipe threads are all right-handed threads, making it impossible to assemble or disassemble the last length of threaded pipe without a union. Pipe unions provide a means of connecting two runs of pipe while making it possible to disconnect the piping when repairs are required. A union should always be installed when the possibility exists that the pipe may need to be disconnected.

REPAIRING STEEL PIPE

Leaks in steel pipe are usually caused by loose connections or by ***corrosion*** (rusting) of the pipe. Loose connections can be tightened, but rusted or otherwise damaged sections must be replaced. Rusted and leaking connections at a fitting are caused by removal of the galvanized coating during the threading procedure. The defective fitting or section usually must be removed and replaced. Pipe repair is shown in Fig. 5-16.

Steel pipe used as a drain line sometimes can be repaired by removing the damaged section and using an adaptor to replace it with rigid plastic pipe. Check local building codes before using this repair procedure, since not all codes permit the use of plastic pipe.

RIGID PLASTIC PIPE

Growth in the use of plastic pipe has been nothing less than spectacular in recent years. Plastic pipe was once considered basically a "do-it-yourself" material, used chiefly for farm water systems and drains. Now rigid plastic piping is widely used. It is employed in chemical and food processing, natural gas distribution and supply, shipboard installations, laboratory and industrial wastes disposal, municipal water treatment, industrial and residential plumbing, and a host of other applications.

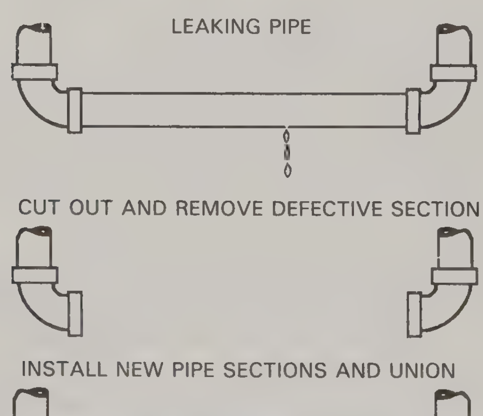


Fig. 5-16. Steel pipe can be repaired by cutting out the defective section, then replacing it with two new lengths of pipe and a union.

Despite the growing popularity of this material, it is sometimes difficult to obtain reliable, up-to-date and comprehensive information. When in doubt, consult your local building codes before installing plastic pipe. Some communities lag behind in updating their building codes to permit the use of plastic pipe. On the other hand, building inspectors and local plumbing suppliers in many cities are well-informed on the latest advances in the use of plastic piping, and where its use is permitted.

Plastic pipe has become an acceptable and inexpensive means of transferring many types of liquids, and is replacing steel pipe in many applications. Plastic piping has outstanding resistance to nearly all acids, caustics, salt solutions, and other corrosive liquids. It does not corrode, rust, scale, or pit on inside or outside surfaces. It does not rot, and resists growth of bacteria, algae, and fungi that could cause offensive odors or create serious sanitation problems.

Since its inner wall is very smooth, plastic piping provides maximum flow rates and abrasion resistance at lowest cost, and exhibits minimal buildup of sludge and slime.

Plastic pipe is tough and strong. It has tensile and burst strengths sufficient to handle the operating pressures that fall within the temperature range of the plastic used to make it. However, as the temperature increases, the burst point becomes lower.

Rigid plastic pipe is easier to handle, join, and install than metal piping, and is less expensive as well. The low material cost and labor-saving factors account for the extreme popularity of rigid plastic pipe.

TYPES OF PLASTIC PIPE

There are three types of rigid plastic pipe.

1. ***ABS*** (acrylonitrile-butadiene-styrene) plastic pipe and fittings are black in color and are used only for drain, waste, and vent piping. There are two grades of ABS, Schedule 40 and Service. Building codes generally require Schedule 40.
2. ***PVC*** (polyvinyl chloride) plastic pipe is white in color and used for cold water supply or drain lines. PVC pipe is rated at a temperature of 73°F and a pressure of 100 psi. PVC pipe and fittings are available in diameters from 3/8 in. to 16 in., and in two grades, Schedule 40 and Schedule 80.
3. ***CPVC*** (chlorinated polyvinyl chloride) plastic pipe is tan-colored, and can be used for hot and cold water lines or drains. Only CPVC can be used for both hot and cold water piping, provided local building codes permit. CPVC is available in two grades, Schedule 40 and Schedule 80. It is rated to take a water pressure of 100 psi at a temperature of 180°F.

Pressure-rated plastic pipe is designed for water supply, but can be used for drains. Pressure-rated pipe provides a complete system with pipe of uniform strength. Plastic piping is *never* used within the refrigeration system itself, but often replaces steel pipe normally used for drains or support systems.

PLASTIC PIPE SIZES

Rigid plastic pipe and fittings are manufactured to conform to nominal pipe sizing of steel pipe, with matching outside diameters. The inside (flow) diameter of plastic pipe changes slightly with the "Schedule" number. Both Schedule 40 and Schedule 80 plastic pipe have the same outside diameter, but the Schedule 80 pipe has a *thicker wall*. The thicker wall of Schedule 80 plastic pipe allows it to be threaded like steel pipe. However, it can also be solvent-welded like Schedule 40 material. The Schedule 80 pipe is a heavier duty material than Schedule 40; the difference can be compared to that between Type L and Type K copper tubing.

Schedule 40 PVC and Schedule 40 CPVC are the most commonly used types of plastic pipe. Both are available in 20-foot lengths. Schedule 40 pipe and fittings are joined by using a solvent cement. Do not attempt to thread Schedule 40 plastic pipe–its walls are too thin.

SOLVENT WELDING

The major difference between plastic pipe and steel pipe is the method used for joining. Steel pipe is joined *mechanically* using threaded fittings; plastic pipe is joined by a *chemical* process called ***solvent-welding.*** The solvent-welding assembly process is much faster and easier, resulting in desirable labor savings.

Solvent-welding (commonly referred to as "cementing") is a simple operation, but each detail of the procedure is important and must be followed closely. Over 90 per cent of PVC or ABS pipe joint failures are due to poor cementing techniques or to outright carelessness. It is important to follow instructions carefully and not take any shortcuts. Properly joined, PVC and CPVC pipe and fittings produce pressure-tight joints, whether those joints are made in the shop or in the field. Some skill and knowledge are required to obtain joints of consistently good quality.

Using solvent cement

Solvent cement is normally purchased in one-pint metal containers with an application dauber attached to the lid. Each type of plastic pipe and fittings has a different chemical composition; a different solvent cement is required for each type, and should be used **only** with that material. Solvent materials are described briefly below.

- **ABS:** Used with all sizes of Service and Schedule 40 ABS pipe and fittings.
- **CPVC:** Used with all sizes of Schedule 40 and Schedule 80 CPVC pipe and fittings.
- **PVC:** *Light Duty*. Used with Schedule 40 pipe and fittings 6 in. or smaller in diameter. *Heavy Duty*. Used

with Schedule 80 pipe and fittings 6 in. or smaller in diameter. *Extra Heavy Duty*. Used with all PVC pipe and fittings 6 in. or larger in diameter.

- **Primer:** Used before solvent-welding to clean and soften the bonding surfaces of rigid plastic pipe and fittings.

When not in use, solvent cement containers should always be covered to prevent excessive evaporation. Do not use thinner–cement that is lumpy and shows signs of thickening should be discarded.

Special care must be exercised if two different types of plastic pipe are to be joined. Local codes usually forbid such combinations unless a mechanical joint or special adaptor is used.

Using solvent cements safely

WARNING: Solvent cements and primer are extremely flammable and give off vapors that are dangerous when ventilation is inadequate. They are harmful if swallowed and fumes can cause eye irritation. Repeated or prolonged skin contact causes skin irritation.

Keep away from heat, sparks, and open flame. Use only with adequate ventilation. Avoid contact with eyes, skin, and clothing. Avoid prolonged breathing of vapor. Close container after each use.

FIRST AID: In case of *skin* contact, flush with water; for *eyes*, flush with water for at least 15 minutes and seek medical attention. Wash contaminated clothing before reuse. If *swallowed*, **do not induce vomiting**. Call a physician immediately.

PIPE PREPARATION

Proper preparation of rigid plastic pipe for joining is important to achieving a satisfactory installation. Pipe must be cut square, burrs removed, and ends beveled to ensure that joins will be properly solvent-welded and leakproof.

Cutting

Plastic pipe can be easily cut with almost any type of saw, but for best results, a fine-tooth blade should be used. For proper square end cuts, a miter box should be used, Fig. 5-17. Pipe cutters may be used when the cutting wheel is designed for use on plastic pipe. Also available are plastic pipe cutters that are similar to pruning shears in appearance, Fig. 5-18. These cutters are rapidly gaining popularity.

Deburring and beveling

All burrs, chips, and other loose material must be removed from both the inside and outside surfaces of the pipe before joining is attempted. Use a knife, deburring tool or a half-round, coarse file to remove all burrs.

All pipe ends should be beveled to approximately the dimensions shown in Fig. 5-19. Beveling makes it easier

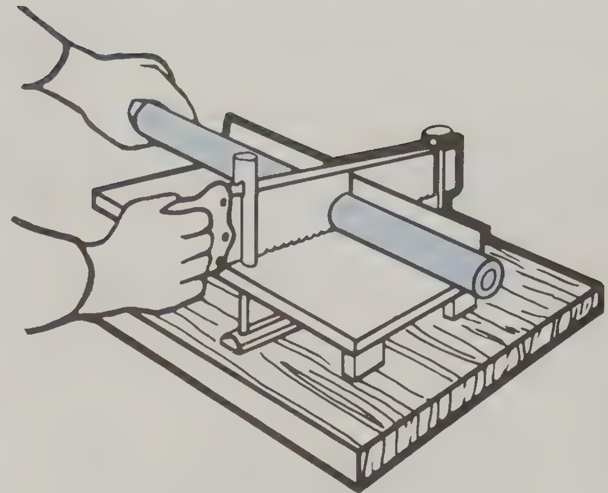


Fig. 5-17. For clean, square-cut pipe ends, use of a miter box is recommended. A fine-tooth sawblade will give the best results. (Nibco)

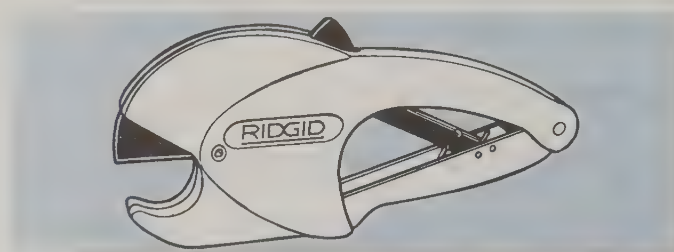


Fig. 5-18. A plastic pipe cutter similar to pruning shears is rapidly gaining acceptance. It provides quick, clean, one-handed cuts for plastic pipe up to 1 1/2 in. OD. (The Ridge Tool Company)

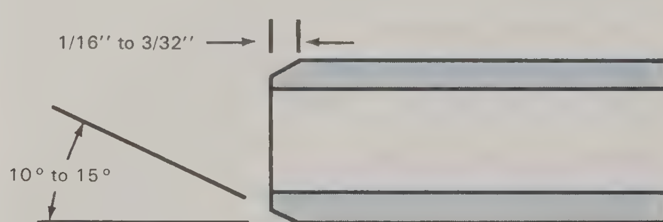


Fig. 5-19. For easier assembly of fittings to pipe, the cut end of the pipe should be beveled as shown. The bevel will also help prevent scraping of solvent from the fitting socket when the pipe is inserted. (Nibco)

to socket the pipe in the fitting, and minimizes the chance of wiping solvent cement from inside the fitting when the pipe is inserted.

Cleaning and priming

Surfaces to be solvent-welded must be clean and dry. Use a clean cloth to wipe away all loose dirt and moisture from inside and outside surfaces of the pipe end. Also wipe inside the socket of the fitting.

The function of the primer is to penetrate and soften the bonding surfaces of plastic pipe and fittings. Primer

is a high-strength product that penetrates rapidly. It is very effective on the hard-finished, high-gloss products now being produced.

Apply primer to the pipe end with a dauber or a natural-bristle paint brush for a distance of approximately one-half the pipe diameter. Using a rag to apply primer is not recommended, since repeated contact with skin may cause irritation or blistering.

Next, apply primer freely to the socket of the fitting. Keep the surface wet and applicator in motion 5 to 15 seconds. Redip the applicator as necessary. In cold weather, allow more time for proper penetration before applying the cement to the joint.

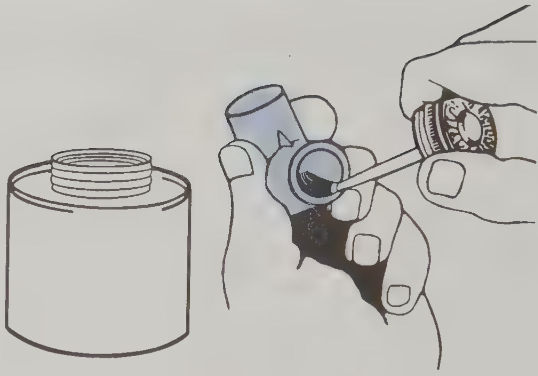


Fig. 5-21. A full, even coat of solvent cement should be applied inside the fitting's socket. Avoid excessive application, which could restrict flow in the fitting. (Nibco)

MAKING PLASTIC PIPE JOINTS

When properly solvent-welded, plastic pipe joints will be mechanically strong and leakproof. The solvent cement used to make the joints actually softens the two mating surfaces to the point where they fuse together. When the solvent evaporates, the pipe and fitting are, in effect, one piece.

Applying cement

First, apply a generous coating of cement once around the entire outside surface of the pipe to a width slightly more than the socket depth of the fitting. See Figure 5-20. Use the dauber supplied with the cement or a natural bristle brush (the solvent in the cement could dissolve synthetic bristles). Do not worry about excess cement on the pipe. The excess cement will be forced out as a bead when the pipe is inserted into the fitting.

Next, apply a full even layer of cement once around the inside socket of the fitting, Fig. 5-21. Avoid using excess cement, however. Such an excess inside the socket could be pushed into the fitting and form an unwanted restriction to flow through the system.

Joining pipe and fitting

Immediately after applying cement to both pieces, insert the pipe to the full socket depth of the fitting. While inserting the pipe, rotate it (or the fitting) about 1/4 turn to ensure complete and even distribution of the cement. Hold the joint firmly together for a **minimum** of 20 to 30 seconds, as shown in Fig. 5-22. This will prevent the pipe from moving or "backing out" of the socket until the cement has set sufficiently to prevent movement. Do not move the newly cemented joint for about two minutes after joining.

Do not attempt to solvent weld under the following conditions:

- If it is raining (surfaces must be clean and dry).
- If the temperature is below 40°F.
- If under direct exposure to sun at temperatures above 90°F.

Do not discard empty primer or solvent cans, brushes, or daubers near plastic pipe. Concentrated fumes or drippings from such material could soften the pipe and cause it to fail.

FITTINGS FOR PLASTIC PIPE

Plastic pipe fittings are readily available in all types and sizes, and use the same names as those applied to fittings for steel pipe. See Fig. 5-23. Do not mix *types* of plastic pipe and fittings: use ABS pipe with ABS fittings, PVC pipe with PVC fittings, Schedule 40 pipe with Schedule 40 fittings, and so on. Dissimilar types of

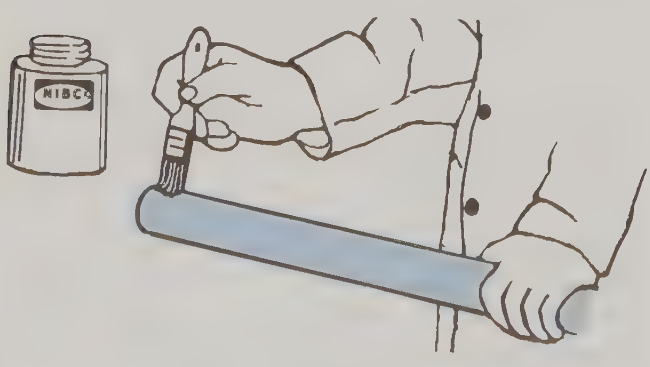


Fig. 5-20. Apply solvent cement to the end of the pipe for a distance slightly greater than the depth of the fitting's socket. (Nibco)

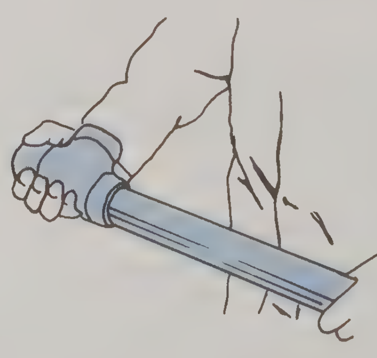


Fig. 5-22. Twist the joint 1/4 turn as it is being assembled, and hold it in position until the cement begins to set. Correctly made solvent-welded joints will be leakproof and mechanically strong. (Nibco)

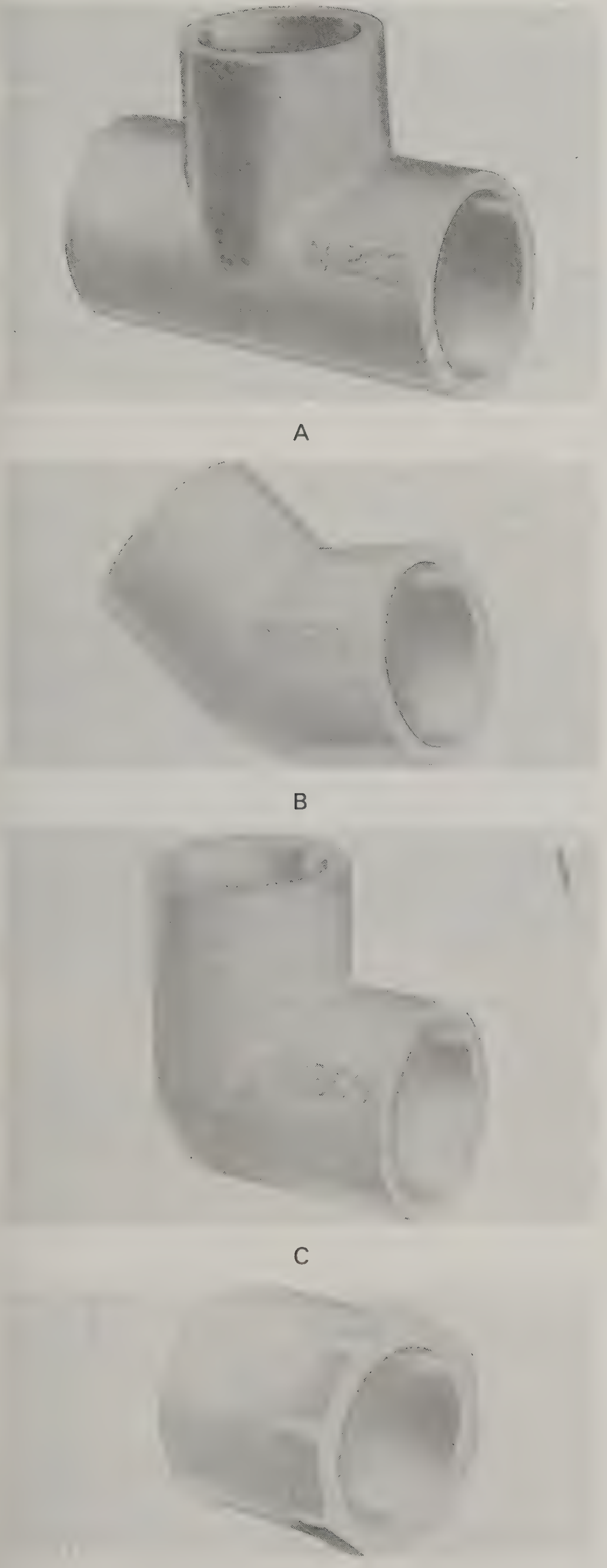


Fig. 5-23. Fittings for rigid plastic pipe. A–Tee fitting. B–45° elbow. C–90° elbow. D–Bushing. (Nibco)

plastics will not bond together properly, allowing leaks to develop.

REPAIRING PLASTIC PIPE

Leaks in plastic pipe usually are repaired by cutting out the defective section of pipe and replacing it. Often, this can be done by simply inserting a coupling. An example of such a repair is shown in Fig. 5-24. Be certain to use the same type of plastic pipe and the correct solvent cement.

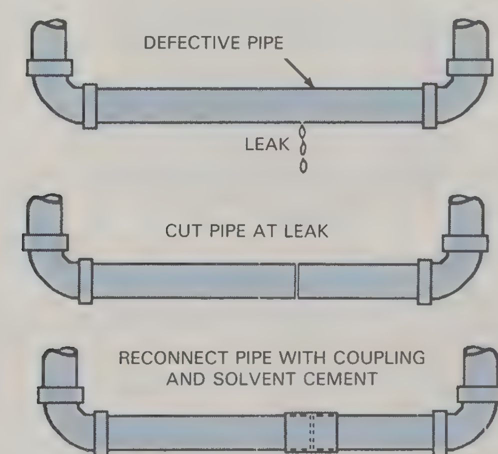


Fig. 5-24. Repairing a leak in plastic pipe involves cutting out the defect and installing a coupling or short section of new pipe.

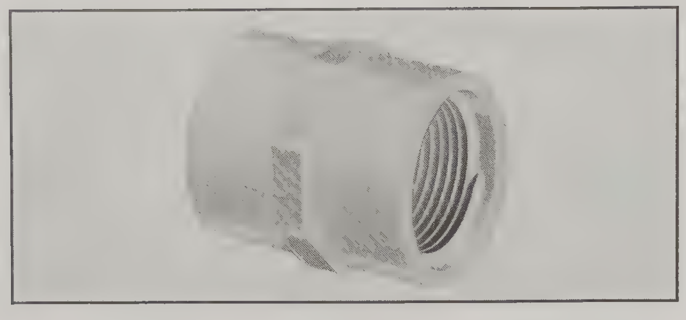
ADAPTORS

Sometimes, it is necessary to connect from one type of pipe or tubing to another (for example, steel pipe to PVC or copper tubing to steel pipe). Special fittings, called ***adaptors***, are available for quickly and easily making such connections. See Fig. 5-25. These adapters can be elbows, tees, or couplings in various combinations of male or female fittings. Most any combination is possible in adaptors.

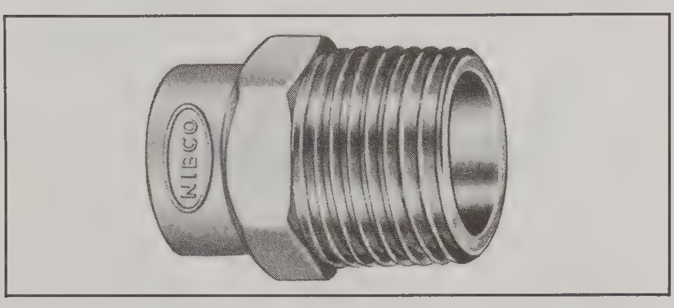
SUMMARY

This chapter explained the various tools and materials used when working with steel or plastic pipe. Such piping is often used for drains and condensate lines. Pipe (both steel and plastic) is cheaper than copper tubing, and is easier to install. Piping in drainage applications is not under high pressure and is less subject to leaking.

Every tool is designed to perform a specific job, if used properly. The same is true of materials. Knowledge eliminates guessing, and practice develops skills. Skills are acquired through *knowledge* and *practice*, and these skills are valuable. This chapter was intended to produce the knowledge needed to develop the necessary skills for working with steel and plastic pipe.



A



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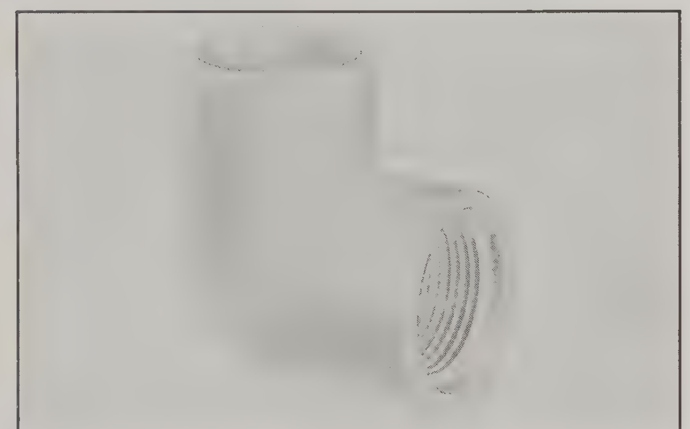


C

Fig. 5-25. Adaptors used with plastic pipe. A–Coupling, plastic to female pipe thread. B–Coupling, tubing (solder joint) to male pipe thread. C–Elbow, plastic to female pipe thread. (Nibco)

The HVAC technician must be skilled in many areas to perform the variety of tasks required in this field. Working with different systems and equipment eliminates boring repetition, but the technician must be prepared for this variety. Most companies start new employees on installation jobs that required the skills discussed in this chapter.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name two types of steel pipe.
2. Nominal pipe sizes are measured by ________ diameter.
3. Is ACR copper tubing 1/8 in. larger or 1/8 in. smaller than nominal?
4. Pipe thread is tapered ________ for every inch of length.
5. What tool is used to remove burrs from steel pipe?
6. The tool used to cut threads on steel pipe is called a ________.
7. Fittings called ________ are used to change the direction of piping run.
8. What fitting is used to connect pipe in a straight line?
9. Low ________ ________ and ________-________ factors are major reasons why rigid plastic pipe is widely used.
10. ________ plastic pipe is used for drains.
11. ________ plastic pipe is used for cold water supply and drains.
12. ________ plastic pipe is used for hot and cold water supply and drains.
13. Plastic pipe and fitting sizes are ________ sizes.
14. Plastic pipe is joined by ________ welding.
15. ________ are used to change from one style of pipe to another.

Chapter 6

SOLDERING

After studying this chapter, you will be able to:
- *Describe the use of air-fuel torches.*
- *Use fuel gas cylinders and torches properly and safely.*
- *Connect and operate pressure regulators correctly.*
- *Select proper alloys and fluxes.*
- *Describe how to solder connections properly and safely.*

NEW WORDS

acetone	MAPP
acetylene	MPS
brazing	plastic range
capillary action	pressure regulator
epoxy	soft soldering
ferrous	solder
fillet	soldering
flux	solidus
hard soldering	tare weight
heat sink	tinning
liquidus	

SOLDERING SKILLS

The ability to make strong, neat, and leakproof solder connections is a fundamental skill required of every HVAC technician. Learning to make good sweat-soldered connections is not difficult, but you must pay attention to detail .... and practice!

Good sweat-soldered connections must be made quickly and correctly, *on the first try. Too much* heat, or *not enough* heat, will result in a poor connection. Trying to correct a badly made connection is more difficult than starting over.

WHAT IS SOLDERING?

Soldering is the process of joining two pieces of base metal with the use of a filler *alloy* (usually consisting of tin and another low-melting point metal, such as lead). Soldering joins the base metal pieces (which may be the same or different metals) without melting either piece. Only the alloy (the ***solder***) melts. Soldering is an adhesion process that works much like gluing two pieces of wood together. In soldering, the alloy is the "glue;" heat is needed to melt the alloy and cause it to adhere to the surface of the base metals. See Fig. 6-1.

Each soldering alloy is designed so that when its flow point is reached, the molecules of the alloy will penetrate and join with the molecules of the base metal (without *melting* the base metal). For maximum joint strength, the layer of alloy between the base metal pieces should be very thin.

SOLDERING VS. BRAZING

Soldering joins metals at less than 840°F (450°C); joining at temperatures above 840°F is properly called

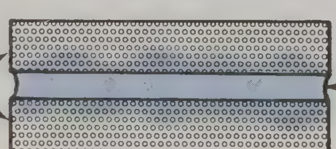


Fig. 6-1. The filler alloy melts and adheres to the surfaces of the base metal pieces, entwining (wrapping around) the molecules of the base metal to form a strong bond.

brazing. The American Welding Society has established this method of distinguishing between soldering and brazing. In the refrigeration industry, however, "soldering" is an all-inclusive term. Usually, the term ***soft soldering*** is applied to joining done at temperatures below 840°F and ***hard soldering*** refers to the higher temperature process that AWS calls brazing.

The following factors determine whether to solder or braze (soft-solder or hard-solder) and dictate the type of alloy to be used:

- The physical properties of the metals being joined.
- The demands that will be placed on the connection after it has been formed.

In refrigeration and air conditioning work, soft soldering is used to install copper water lines and drains. The water lines are not under high pressure and are not subject to vibration. Copper tubing used for refrigeration systems should be hard-soldered (brazed) due to high pressure and vibration.

SOLDERING ALLOYS

Filler metals (solder) can be obtained in a variety of forms: foil, tape, sheets, wire, flux-cored or solid bars, preforms, or paste. One-pound spools, Fig. 6-2, are the most popular for HVAC work. Depending upon the application, different tin/lead or tin/silver alloys are used.

Tin/lead solders

The tin/lead solders form the largest group of filler metals used in soldering. They are used for joining most metals and have good corrosion resistance. There are many different tin/lead alloys because different types are produced to meet various needs: soldering tin, copper, brass, bronze, sheet iron, and sheet steel. Soft-soldering is excellent for conducting heat or electricity and

Fig. 6-2. Lead-free solders like this tin/silver type must be used for joints in any tubing that will carry drinking water. Tin/lead and tin/antimony solders are also available for various applications. (J. W. Harris)

for making leaktight joints, but the resulting joint is not as strong as the base metals it brings together.

The tin/lead solders are **not recommended** for high stress or vibration areas, such as those found on refrigeration systems. Stress and vibration will cause the solder to crack and a leak to develop. Soft-soldering is best used on condensate drain lines and similar non-stress applications.

Selecting the proper soldering alloy is very important. The numbering system indicates the percentage of each metal in the solder. In the tin/lead group, for example, 50/50 indicates 50% tin and 50% lead, and 60/40 indicates 60% tin and 40% lead. These solders were formerly used by plumbers on copper water lines or drains, but are no longer permitted in drinking water applications. Lead-free alloys that do not present a human health hazard must be substituted. Tin/lead solders are still used in other plumbing and HVAC applications. The 50/50 solder has a melting point of 360°F (182°C), and a flow point of 420°F(216°C). The 60/40 solder is slightly stronger and will melt at 360°F (182°C) and reaches the flow point at 375°F (191°C).

Tin/lead solders may contain small amounts of other metals to produce special properties. Metals often added to solders are: antimony, bismuth, and silver. Antimony increases the strength of a solder. Where a stronger joint is desired for copper tubing, or where a lead solder cannot be used, a 95/5 tin/antimony alloy is often chosen. This solder has a melting point of 452°F (233°C) and a flow point of 464°F (240°C).

The 95/5 tin/antimony alloy should not be used on brass or galvanized metal. When antimony is in a molten state, it will absorb zinc from the brass or galvanizing, resulting in a very brittle joint. This alloy is higher in strength and elongation (stretch factor) than the tin/lead solders, but (like tin/lead) it has proven unsatisfactory for applications involving stress and vibration. For reasons not yet known, this alloy tends to powder over a period of time.

Bismuth and silver are added to improve the ***tinning***, or spreading, action of the solder. Bismuth is used for lower-temperature alloys and silver for higher-temperature solders.

Tin/silver solders

Another major group of solders is the tin/silver alloys. These silver-bearing solders are widely used for the greater strength of the connection they form. Also, the lower working temperatures eliminate the weakening of base metals caused by annealing (from higher soldering temperatures). The oxide scale formed by the higher temperature is also eliminated.

The silver-bearing alloys have excellent ability to bond with both ***ferrous*** (iron-containing) and nonferrous metals. These solders work very well for joining dissimilar metals (such as iron to copper), and have good elongation (stretch factor) for use where vibration

SOLDERING ALLOYS						
	COMPOSITION PERCENT				TEMPERATURE	
SOLDER	(Sn) TIN	(Pb) LEAD	(Sb) ANTIMONY	(Ag) SILVER	MELTS	FLOWS
50/50	50	50			360	420
40/60	40	60			360	460
60/40	60	40			360	375
95/5	95		5		452	464
silver solder	96			4	430	430
silver solder	94			6	430	535

Fig. 6-3. The plastic range of a solder is the span from its melting point to its flow point, as shown in the right-hand column of this table of common soldering alloys.

is a problem. Melting points for these alloys range from 430°F to 535°F (221°C to 279°C). For applications in the refrigeration industry involving stress or vibration, the tin/silver alloys are superior to both tin/lead and tin/antimony alloys.

The range of temperature between the ***solidus*** (melting point) and the ***liquidus*** (point where it flows as a liquid) of a solder is called its ***plastic range***. Fig. 6-3 shows the composition and plastic range of a number of common solders. A wide plastic range provides easier control of the alloy during the soldering process.

SOLDER FLUXES

A ***flux*** is a chemical used to treat the clean surface of the base metal, to remove oxide from filler metal, to prevent re-oxidation of the material, and to aid the capillary flow of the filler alloy. See Fig. 6-4. In some instances, the appearance of the flux may be used as a temperature guide. There is no single universal flux for all applications. Therefore, choice of the proper flux is very important to the quality of the soldered connection. When selecting a flux for a particular alloy, it is wise to refer to the manufacturer's recommendation.

Using fluxes

Thorough cleaning of the base metal joining surfaces is vital to making strong, leakproof, long-lasting joints. The fittings and tubing must be free of oil, grease, rust, or oxides that would prevent the alloy from penetrating the surface of the base metals. Cleaning is accomplished by using a wire brush or fine sandpaper or emery cloth to get down to the base metal, Fig. 6-5. Failing to clean a joint properly wastes time and effort because the alloy cannot "flow" properly or penetrate the base metals.

The flux is designed to maintain a chemically clean surface during the soldering operation. Its purpose is not to clean the metal initially, but to keep the joint free of oxides during the soldering process. The flux dissolves any oxides that form due to oxygen contacting the molten alloy or the hot base metals. It is most important that the flux remains in place during the soldering operation. It must not be blown away or vaporized before the process is completed. The time required to solder a joint must be kept to a minimum, because more time means more heat and more heat means more oxides.

As noted, fluxes must serve several functions, all of which must be performed well to provide a sound connection. In addition to removing surface oxides and acting as a shield against new oxides, the flux must increase the "flow" properties of the alloy, and yield to the alloy as it is melted into the joint.

Fig. 6-4. This liquid soldering flux removes oxidation from copper tubing, as seen in the photo. It prevents new oxidation from taking place during the soldering process. (J. W. Harris)

Fig. 6-5. Wire brushes and sandpaper or emery cloth should be used to clean tubing and fittings before they are soldered. Brushes are made specifically for common fitting sizes, and should be used only for fittings of the specified size. (Malco)

The choice of flux to be used in any soldering process is determined by the metals being joined, and the filler alloy being used. Since there are many solders and fluxes, follow the manufacturer's recommendations on which flux is best for each situation. Flux should be applied with care; the solder will flow where the flux has prepared the way.

Special care must be exercised when using fluxes to solder copper tubing or brass fittings in a refrigeration system. Fluxes are very harmful when inside tubing of the refrigeration system, so excess flux should be avoided and only the thinnest possible film should be applied.

The flux best suited to the 50/50, 95/5, and the tin/silver solders is the noncorrosive type in the paste form. This flux consist of zinc chloride (with perhaps a trace of ammonium chloride) mixed into a petroleum jelly. When this flux is heated, it first loses the moisture, then melts and partly decomposes to form hydrochloric acid. This acid dissolves the oxides, floats them out ahead of the molten solder, and promotes the capillary action of the solder joint.

Flux is applied only to the portion of the tubing that is to be inserted into the fitting. Do *not* apply flux to the fitting socket. As shown in Fig. 6-6, paste-type flux should not be applied close to the cut end of the tubing. Flux should remain back from the end about 1/8 in. (3 mm). The tubing is then inserted into the fitting and rotated to spread the flux evenly. This procedure prevents excess flux from entering the fitting and contaminating the refrigeration system. Flux is applied to the tubing only; do not apply flux to the socket.

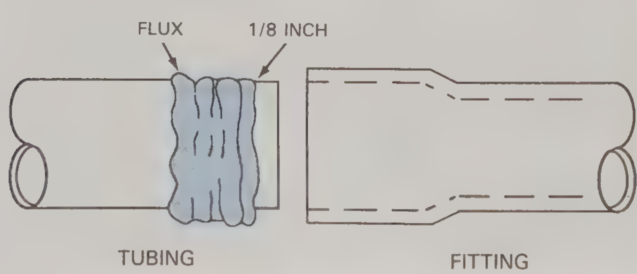


Fig. 6-6. Flux should be applied to the tubing, not the fitting. As shown, approximately 1/8 in. of tubing at the cut end should not be fluxed. This will help avoid contaminating the system with soldering flux.

Although it is commonly used in other types of soldering, an acid flux composed of 71% zinc chloride and 29% ammonium chloride should *never* be used in refrigeration work. Using such a highly corrosive flux on a refrigeration system is simply asking for trouble.

When soldering electrical connections, a special noncorrosive flux is used. This is a *rosin* flux that is produced from the tar found in pine trees. Sometimes activators are added to rosin flux to improve its spreading action.

FUEL GASES

The melting of the alloy (filler metal) and the heating of the base metals is normally done with a fuel gas torch. In these torches, a fuel gas is mixed with atmospheric air (21% oxygen) to produce a soldering flame. Flame temperature is determined by the type of fuel gas used. ***Acetylene*** produces the highest temperature, followed by ***MPS*** or methylacetylene-propadiene stabilized gas, (often referred to by its trade name, ***MAPP***). Gases such as propane, butane, natural gas, and manufactured gas produce lower temperatures, roughly in that order.

THE AIR-ACETYLENE TORCH

The air-acetylene torch, Fig. 6-7, combines fuel gas from a cylinder with combustion air drawn from the atmosphere. Because atmospheric air contains only 21 percent oxygen, the air-acetylene torch produces a low-

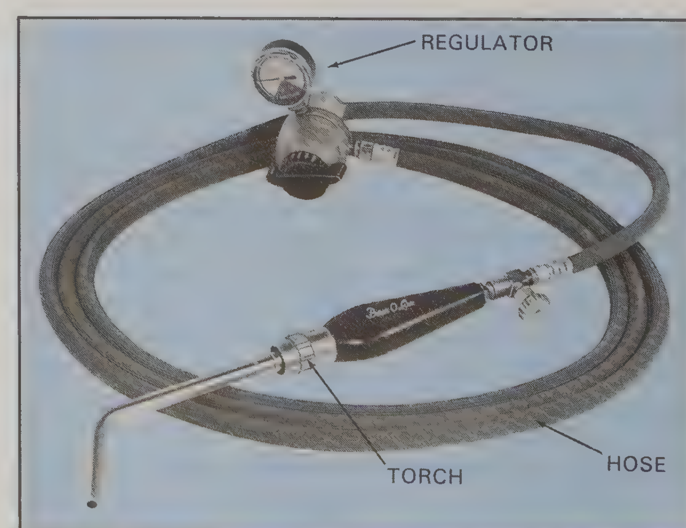


Fig. 6-7. Combustion air combines with fuel gas at the tip of the air-acetylene torch. (Prest-O-Lite)

temperature flame. The low heat levels used in soldering reduce stress on the base metals, as well as reducing the formation of oxides inside the tubing. This makes the air-acetylene torch the ideal tool for soft-soldering procedures.

ACETYLENE

Acetylene is a colorless gaseous hydrocarbon made by the chemical reaction of water and calcium carbide. It is two parts carbon and two parts hydrogen, so its chemical formula is C_2H_2. It is used chiefly in soldering, brazing, and welding work. When burned with oxygen, acetylene will produce the highest flame temperatures obtainable (approximately 5660°F or 3093°C).

Acetylene cylinders

All acetylene cylinders are manufactured to Department of Transportation (D.O.T.) requirements. See Fig. 6-8. They are thoroughly tested by the D.O.T. Bureau of Explosives before being used commercially. A fusible plug located in the bottom of each cylinder will melt at approximately 212°F (100°C) to relieve dangerous pressure buildup.

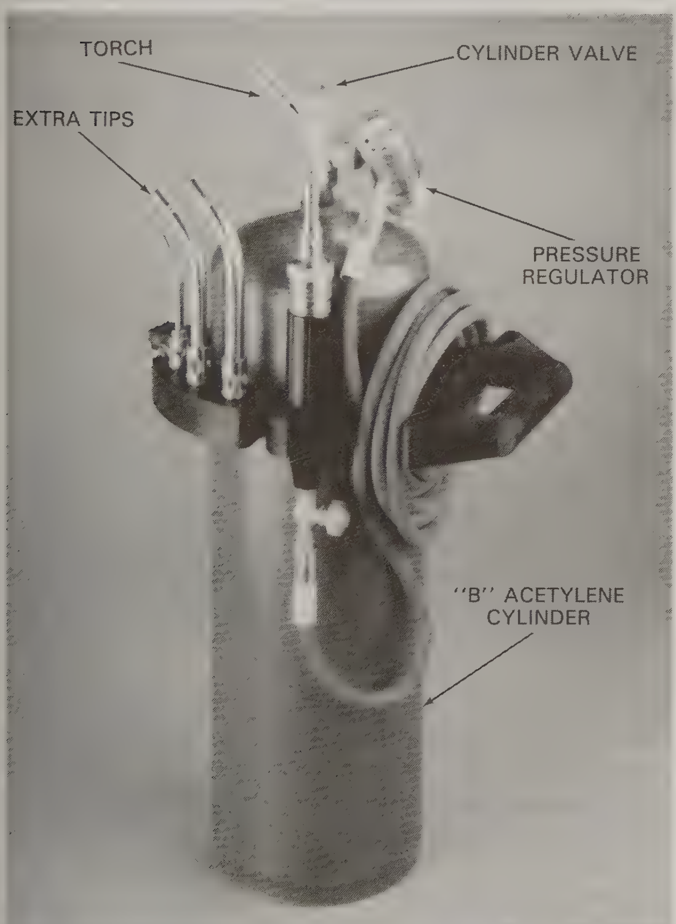


Fig. 6-8. A typical air-acetylene torch outfit for soldering is used with a "B" cylinder. All acetylene cylinders must be tested and approved for use. (Thermodyne)

Acetylene can be unstable, unsafe, and explosive at pressures above 15 pounds per square inch. However, the gas can be safely stored in cylinders at a higher pressure because of the method described below. Understanding this method of storage is necessary for safe operation of acetylene torches.

The cylinder is filled with a porous substance that will absorb ***acetone***, a liquid solvent. A precisely measured amount of acetone is then introduced into the cylinder to be absorbed by the porous substance. The cylinder, containing the porous material and acetone, is then weighed. This weight is stamped onto the cylinder. This is the ***tare weight***, or weight of the container before being filled with acetylene.

When acetylene is pumped into the cylinder, it is absorbed by the acetone. It is believed the acetylene molecules fit in between the acetone molecules. As pressure is relieved during use, the acetylene gas is released to flow out of the torch.

Acetylene cylinders should be used in the upright position to avoid loss of acetone and poor flame quality. Each time the cylinder is returned to be refilled, the tare weight should be checked and acetone added as needed.

Acetylene cylinders, often called *tanks*, are available in various sizes, Fig. 6-9. The smallest cylinder, MC, contains 10 cu. ft. of acetylene. "MC" stands for Motor Car — these cylinders were originally used to fuel acetylene-burning car and motorcycle headlights. The next larger cylinder, B, contains 40 cu. ft. of acetylene.

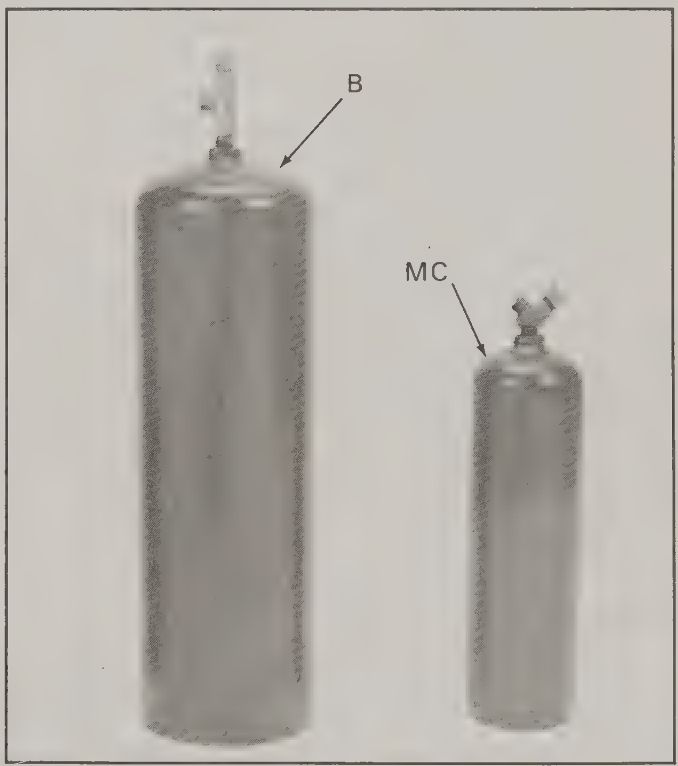


Fig. 6-9. Common acetylene cylinder sizes are B and MC. The B cylinder holds 40 pounds of acetylene; the MC cylinder holds 10 pounds. (Uniweld)

The MC and B cylinder sizes are the most frequently used by service technicians, but larger cylinders are occasionally used on major installation jobs. Each acetylene cylinder is equipped with a valve that has a threaded outlet for installing a pressure regulator. Cylinders have different size valve openings: small-size pressure regulators cannot be installed on large cylinders.

Safety precautions with acetylene

Safety is an aspect of good craftsmanship, and basically involves the use of common sense. Observing the following precautions will help you use acetylene safely.

1. Never permit fuel gas to escape and accumulate. Acetylene concentrations of from 3% to 90% in air or oxygen are explosive.
2. Never store acetylene or other fuel cylinders in a closed unventilated area. Do not expose tanks to high temperatures or sources of ignition.
3. When setting up an air-acetylene torch, check all fittings with soapy water solution for possible leakage. A leak will blow bubbles. A good soapy solution is easily made by diluting concentrated dishwashing detergent with water on a 1:1 ratio. A squirt-type dispenser is very handy for applying the solution. *Never use a flame to detect leaks.* Do not use the torch until all fitting leaks have been eliminated.
4. Never use a cylinder that is leaking acetylene. If gas leaks around the valve stem when the valve is opened, close the valve and tighten the packing nut. This compresses the packing around the valve stem and should stop the leak. If the leak does not stop, close the cylinder valve, tag the cylinder as a "leaker," and return it to your supplier. Keep the "leaker" away from all sources of ignition.
5. Never open the acetylene cylinder valve more than 1/2 turn.
6. Always leave the valve key or wrench on the valve stem while a cylinder is in use, so the acetylene can be quickly turned off in case of an emergency. Never use pliers or a wrench on the cylinder valves. Use only the proper valve key or valve key wrench. Always close the cylinder valve and regulator when work is completed.
7. Handle all fuel cylinders with care. Do not drop or roll them.
8. Never allow the torch flame or electric arc to contact the cylinder.

PRESSURE REGULATORS

An acetylene cylinder is pressurized to 250 psi (1274 kPa) at 70°F (21°C). A *pressure regulator*, Fig. 6-10, is used to reduce cylinder pressure to working pressure. The working, or flow, pressure will vary according to the type of torch tip being used, but 5 psi (34 kPa) is considered normal.

Fig. 6-10. A two-gauge acetylene pressure regulator. The cylinder gauge show the acetylene level, while the flow pressure gauge provides a reading of the pressure being supplied to the torch. Pressure is adjusted by rotating the handle on the front of the regulator. (Uniweld)

Pressure regulators are available with either one or two gauges. The single-gauge regulator shows working pressure (or flow pressure) traveling through the hose to the torch tip. This working pressure is adjustable by means of a knob or handle located on the front of the pressure regulator. On two-gauge models, the second (*cylinder*), gauge shows the level of acetylene in the cylinder (full, 3/4, 1/2, 1/4, or empty).

The pressure adjustment on a regulator is designed to open and close in directions opposite those of ordinary valves: turning the adjustment knob counterclockwise will *close* the pressure regulator; clockwise rotation will *open* the regulator.

Acetylene regulators and gauges are color coded red and have special cylinder connections to eliminate confusion with other types of regulators. The outlet hose connection on the acetylene regulator is a special *left-hand threaded* male fitting. The hose fitting can be either a small ("A") or larger ("B") size.

ACETYLENE HOSE

The female hose fitting screws onto the male fitting of the regulator outlet. All acetylene connections are left-hand threads to prevent the user from mistakenly

connecting the hose to oxygen, which has much higher pressure. Left-hand threaded fittings are readily recognized because of the notches, or grooves, cut around the middle of the outside edges of the nut. See Fig. 6-11.

Acetylene hose is a special grade designated with the letters RM. The hose is red in color and is measured by the inside diameter (ID). It is available in 3-, 6-, 12 1/2-, or 25-ft. lengths. The light duty and medium duty hoses are 3/16 in. ID; the heavy duty is 1/4 in.

The connector used on the hose ends is available in either of two sizes, depending on intended use. Most technicians prefer size "A," which is considered a light duty (also called "aircraft" type) hose. It has a 3/8-24 female nut with a left-hand thread. Size "B," for medium or heavy duty use, has a 9/16-18 female nut with left-hand threads. Adaptors are available for connecting the two fitting sizes.

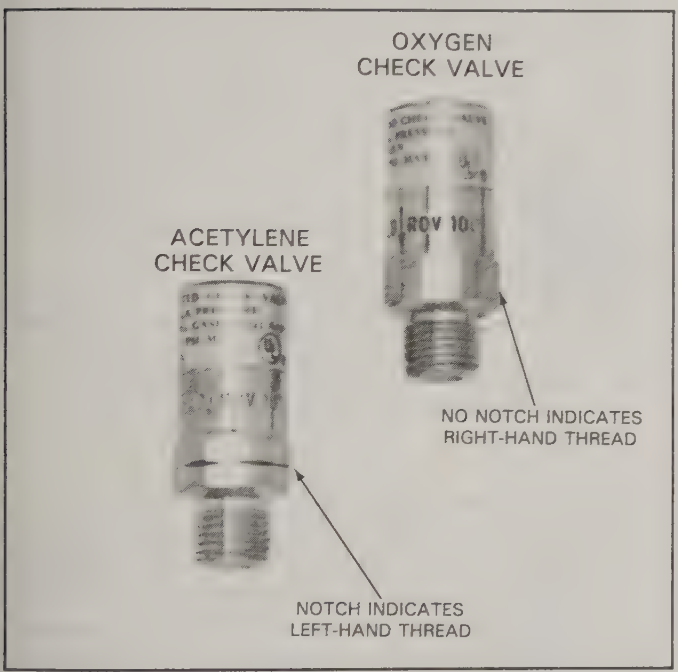


Fig. 6-11. Check valves are a safety device used to prevent the reverse flow of gases. The connectors for oxygen and acetylene are different to prevent accidentally interchanging them. The acetylene valve, at left, has a left-hand thread and is identified by a groove or notch around the nut. The oxygen valve, at right, has right-hand threads and no notch or groove. (Uniweld)

AIR-ACETYLENE TORCH HANDLES

The torch handle has a threaded connection for the acetylene hose at one end, and a threaded connection for a torch tip on the other, Fig. 6-12. The handle also contains a finger-operated valve to control and adjust gas flow. The valve is designed to be opened and closed easily by a twisting motion of two fingers. The valve should not be overtightened, since valve seat damage could result.

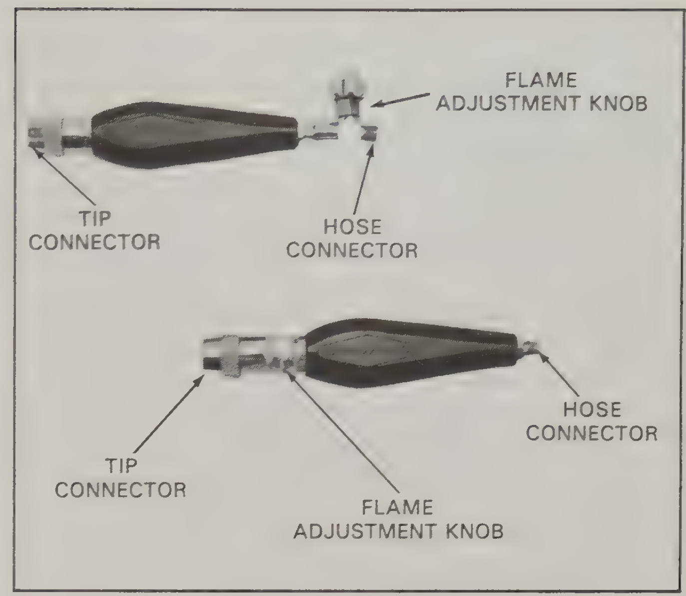


Fig. 6-12. Air-acetylene torch handles include connections for the acetylene hose at one end and for the torch tip at the other. As shown in the two examples, a finger-operated knob for flame adjustment may be at the hose end of the handle, or at the tip end. (Uniweld)

AIR-ACETYLENE TORCH TIPS

Different sizes and styles of torch tips are available for varying applications. See Fig. 6-13. The tips can be easily interchanged in the torch handle by loosening a lock nut, then unscrewing the tip. No tools are needed.

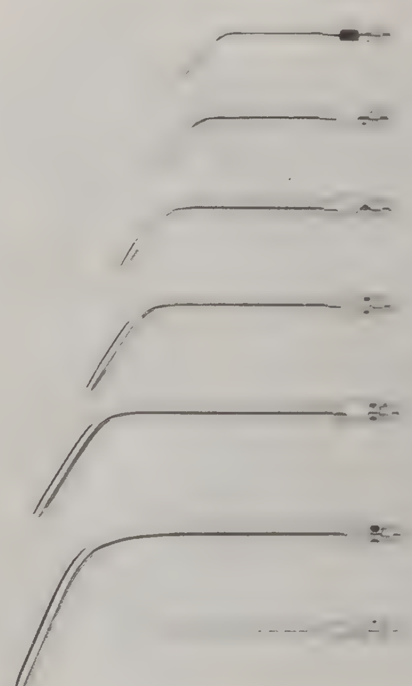


Fig. 6-13. Air-acetylene torch tips are available in a variety of sizes for different applications. (Uniweld)

LIGHTING THE TORCH

The procedure for lighting an air-acetylene torch is quite simple, but certain steps must be followed each time to ensure proper safety. The steps used for this procedure are:

1. Inspect the equipment for any damage and make certain that all valves and regulators have been turned off.
2. Open the cylinder valve slowly, using the proper valve key wrench. Open this valve about 1/4 to 1/2 turn counterclockwise. Leave the wrench on the valve stem so the cylinder can be turned off quickly. If the pressure regulator is the two-gauge type, the contents gauge will immediately register the level of acetylene in the cylinder.
3. Open the torch handle valve one-half turn. Slowly turn the pressure regulator adjusting screw clockwise until the delivery gauge indicates five psi (34 kPa) flow pressure. Vent the escaping gas safely.
4. Turn off the torch handle valve, using finger tip pressure only. The torch is now adjusted to the correct flow pressure and is ready to be lit.
   CAUTION: Before lighting the torch, be sure the tip is pointed away from any object or person.
5. Slightly "crack" open the torch handle valve. Use a flint striker to ignite the acetylene gas coming out of the torch tip. Hold the striker near the end of the torch tip, but do not block the gas flow, Fig. 6-14. A flint striker is the *only* safe device to use when lighting any torch. **Never** use a match or cigarette lighter.
6. Open the handle valve slowly until the desired flame size is obtained.

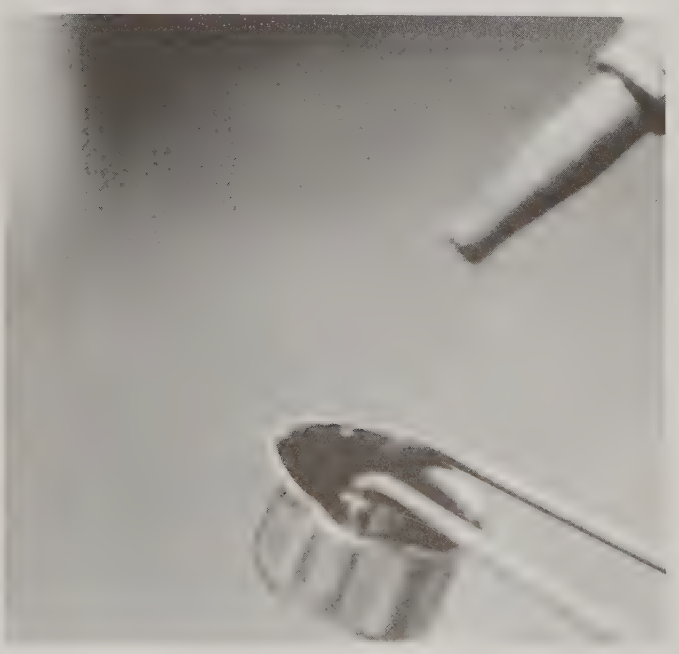


Fig. 6-14. Air-acetylene torches should never be lighted with a match. For safety, always use a flint striker (also known as a spark lighter).

The hottest part of the flame is about 1/8 in. (3 mm) from the tip of the inner cone, Fig. 6-15. Do not restrict the inner cone by holding the flame too close to the workpiece. Such a practice will interfere with proper mixing and combustion of the fuel-air mixture and result in poor flame quality. Once the workpiece is heated to the proper temperature level to melt the solder, the flame is backed away just far enough to maintain the correct flow temperature of the solder.

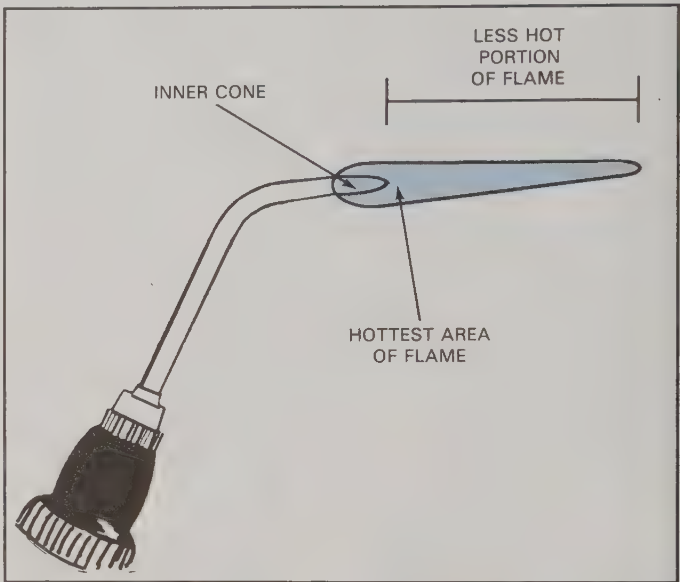


Fig. 6-15. The flame can be adjusted with a knob on the handle. The hottest area of the flame is just in front of the inner cone's tip.

The maximum temperature obtainable with this torch system is 3600°F (1982°C), regardless of the size of tip. The larger tips will provide more *heat output*, but the temperature of the flame remains the same. The workpiece will seldom, if ever, reach this temperature, since solders will usually melt in the range of 400-500°F (204-260°C). Overheating the base metals should be avoided.

SHUTTING OFF THE TORCH

A temporary shutdown of the torch is done by merely closing the handle valve to turn off the flame. The torch can then be laid aside until needed again. However, if the unit is not going to be used for a longer period, it should be completely shut down as follows:

1. Close the valve on the torch handle, using finger tip pressure only. This will kill the flame.
2. Tightly close the cylinder valve.
3. Re-open the torch handle valve to bleed off (release) acetylene from the hose and regulator. Bleeding should continue until both gauges read zero.
4. Turn the adjusting screw on the regulator all the way out (counterclockwise). Closing the regulator

helps to avoid gas loss if the cylinder or torch valves leak.

5. Rewind the hose and place unit in safe storage.

SOLDERING TECHNIQUES

It is of great importance to apply heat properly in any soldering operation. There are a number of heat sources available, such as soldering irons, soldering guns, and various torches, but in this text we will deal only with the open flame technique involving use of the air-acetylene torch. Torch selection is determined by the type and size of soldering to be done. Large tip sizes providing high heat, or even an oxyacetylene torch, may be used by skilled operators. Less-skilled operators should use the air-acetylene torch, with its soft flame and lower temperatures, to avoid overheating the base metals. A variety of tips may be used with this torch and more heat is obtained with the larger tips. Selecting the proper size tip (or flame) requires experience, but in general, small tubing requires a small flame and large tubing requires a large flame. See Fig. 6-16.

Dirty tips or faulty adjustment may produce a sooty flame that deposits carbon on the workpiece. This carbon deposit will prevent the alloy from flowing properly and result in a poor joint.

For consistently good soldering, keep in mind that the alloy will flow properly only when the pieces to be joined are heated equally and evenly to the flow point of the solder. *Do not apply the flame directly to the alloy.* Use the flame to heat the base metals to the melting point of the solder, then back off the flame just far enough to maintain the proper temperature until melted alloy fills the joint. Apply only enough alloy to form a bright shiny bead (a ***fillet***) at the point where the joined pieces meet.

If solder forms a globule or "ball" on the work, rather than flowing smoothly, the base metal temperature may be too low or the joint surfaces are dirty. This can also occur if the torch flame was directed onto the solder and melted a drop off the end. It is very difficult to cause these globules of solder to flow properly.

Key points to remember when soldering are:

- Make the joint fit.
- Clean it thoroughly.
- Apply the proper flux.
- Heat the joint evenly to the correct temperature.
- Apply the proper amount of alloy.

CAPILLARY ACTION

All joints to be soldered should fit tightly for maximum capillary action by the alloy. ***Capillary action*** refers to the process where the alloy automatically fills the gap between the pieces of base metals. It draws the alloy into the full depth of the connection.

To obtain maximum capillary action (and resulting greater strength), the joint to be soldered should be

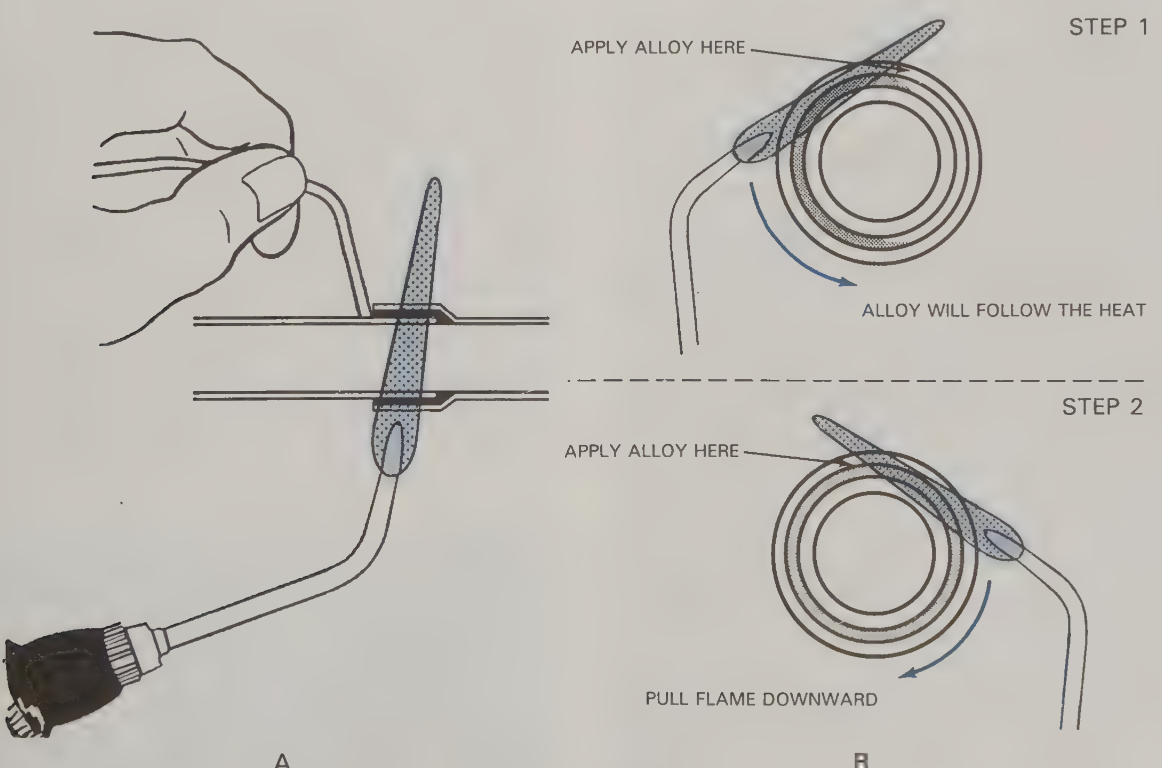


Fig. 6-16. Techniques for soldering small and large tubing. A–Direct flame around bottom of joint for small tubing. Alloy will flow around tubing toward the heat. B–For large tubing, work the flame slowly around the tubing as shown, applying small amounts of filler alloy.

close-fitting all around and well-supported to prevent movement. When the filler alloy enters the joint, the alloy molecules have a greater attraction for the base metal than for each other. The alloy is attracted to each wall of the base metal and "walks" itself into the fitting to completely fill the joint.

This capillary attraction makes it possible to solder a vertical alloy-up joint because the alloy will be drawn up into the joint, Fig. 6-17. When soldering a vertical alloy-up joint, heat the tubing first, then apply heat to the fitting. It is important to heat both pieces evenly. If the tubing is overheated, the alloy may run downward, rather than being drawn upward into the joint. Remember, alloy flows toward the heat.

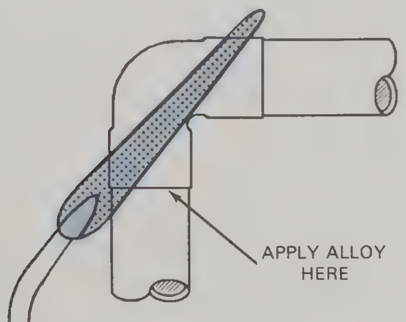


Fig. 6-17. Solder will be drawn up into a vertical joint by capillary action. The alloy will travel toward the heat.

SOLDERING COPPER TUBING

As an HVAC technician, you will frequently have to "sweat solder" copper tubing. Follow the procedures listed below to make mechanically sound and leakproof connections involving copper tubing and fittings.

1. Cut tubing ends square and remove all inside and outside burrs with a reamer. (See Chapter 4.)
2. Clean the copper tubing and fitting thoroughly down to bare metal before making the soldered joint. Joining surfaces must be *clean* to make a sound solder joint.
3. Apply flux to cleaned tubing before soldering. Flux should be applied sparingly and kept away from the tubing end.
4. Always move the torch in short arcs; don't let it remain too long in one spot. Heat tubing first by applying the flame next to the fitting. Heating the tubing first will conduct heat inside the fitting. Work the flame around the tubing and fitting to bring temperature up *equally* in the two pieces.
5. Use the flux as a temperature guide. Apply heat until the flux quits bubbling and becomes fluid and clear. Apply heat to the fitting, as well, to be certain flux inside the fitting is also clear. A clear flux indicates the alloy flow temperature is being reached.
6. Back the flame away slightly to reduce the heat level. Sweep the flame back and forth over the assembly to maintain uniform heat in both parts.
7. Apply the alloy. Heat from the base metals should melt the alloy, not the flame. Feed the alloy into the joint between the tube and fitting. It will quickly melt and completely fill the joint area.
8. Remove flame when alloy begins flowing into joint. Do not continue feeding alloy after joint is filled.

TAKING A SOLDERED JOINT APART

Clean and apply flux to the joint you wish to disconnect. Heat the joint (tubing *and* fitting) evenly. When the alloy becomes fluid throughout the joint, the tubing is easily removed. Do not twist or apply force to tubing to remove it. This will cause severe damage to the hot fitting and tubing. To re-solder the joint, clean the tubing end and the inside of the fitting. Apply flux and re-solder the joint.

WARNING: Never apply heat to a line that is *under pressure*. Applying heat increases pressure; the molten alloy and fitting may be blown violently apart. Be sure to release all pressure from the tubing before heating soldered connection.

SOLDERING ALUMINUM

Aluminum is now used for many applications where copper or steel were once standard. Aluminum is an excellent metal for conducting heat and is widely used in the manufacture of evaporators for domestic refrigerators. However, soldering aluminum presents special problems not normally found with other metals.

When soldering aluminum, proper attention must be given to such details as surface preparation, solder composition, temperature, and the application of heat. Soldering pure aluminum and the many aluminum alloys require special techniques and materials. For example, the aluminum used in the manufacture of evaporators is very thin, so heat applied during the soldering process must be precisely controlled. Aluminum and its alloys are weak when hot (a condition called "hot-shortness"). The metal does not give any warning by a change in color as it approaches the melting point. Instead, it will suddenly collapse. For this reason, the metal must be properly supported during the soldering process.

The corrosion resistance of aluminum results from an oxide that forms quickly on the metal's surface when it is exposed to air. To make a sound soldered connection, these oxides must be removed. Also, additional oxides are formed by the application of heat. These oxides have a higher melting point than the aluminum. A special flux is used that will combine chemically with these oxides to form a slag. This slag then rises to the

surface of the molten solder, where it will not interfere with the soldering process.

The melting point of the solder determines the minimum temperature needed to make the connection, because the solder must be melted before it can flow into the joint. The solders used for aluminum have a higher melting point than those used for copper or steel; aluminum, therefore, must be heated to temperatures 100 to 200°F (38 to 93°C) higher than those metals. This increased temperature is the major reason for difficulties in soldering aluminum and the aluminum alloys.

The solders used for aluminum can be placed into four groups: zinc base, zinc/cadmium base, tin/zinc base, and the tin/lead base solders. See Fig. 6-18. All these may contain quantities of other metals used to obtain certain properties or qualities.

The soldering of aluminum requires skill and proper equipment, requirements that can usually be met under carefully controlled manufacturing processes. However, such control is not readily available in the field, where service and repair work must be performed. A typical problem is the aluminum used in the manufacture of evaporators on domestic refrigerators. The metal is very thin, which promotes good heat transfer for the cooling process. Because of the thin metal, however, these evaporators are easily punctured by sharp instruments. Such a puncture will result in the loss of refrigerant and thus stop the refrigerating process. Soldering such a hole in the field is almost impossible, and repairs are time-consuming and expensive. The customer is usually advised to purchase a new refrigerator.

Repairs to the hole in an aluminum evaporator *can* be performed, but not by the soldering process. ***Epoxy*** compounds are readily available for making such repairs in aluminum and have proven to be highly successful. See Fig. 6-19. The box contains all the necessary materials with complete instructions on proper use.

The same epoxy compound can be used to repair leaks in joints between aluminum tubing and copper tubing. The original aluminum-to-copper connection is performed at the factory, using welding techniques that are not available in the field. Sometimes leaks will develop at this special connection. The epoxy compounds provide a satisfactory and reliable means for making the needed repairs.

ALUMINUM	
SOLDER	**MELTING POINT**
ZINC BASE	700°F TO 820°F
ZINC CADMIUM	510°F TO 750°F
TIN ZINC	550°F AND HIGHER
TIN LEAD	450°F AND HIGHER

Fig. 6-18. The alloys used for soldering aluminum have melting points considerably higher than those used to solder copper or steel.

Fig. 6-19. Repairs to aluminum that could not be done in the field with soldering can often be accomplished with epoxy compounds. Epoxies harden quickly and will withstand pressure and the effects of refrigerants. (Watsco)

AIR-ACETYLENE BRAZING

Special tips have been designed for use on the regular air-acetylene soft soldering torch to increase the working temperature of the flame, making it possible to perform some brazing operations. Some of these special tips are constructed with a gas diffuser inside the tip. The diffuser slows the gas flow and causes the flame to start burning and expanding inside the tip. This creates a high velocity gas stream that completes the burning process outside the tip, providing a high-heat working flame. It is important to keep a full gas flow and flame to avoid overheating the tip.

TORCH TIPS FOR BRAZING

A major difference when using these special tips is the operating (flow) pressure of the acetylene. These are high-velocity tips that require 15 psi (103 kPa) operating pressure from the acetylene pressure regulator. See Fig. 6-20. When using these special high-velocity tips, the regulator is usually turned all the way in (fully clockwise), to obtain the maximum pressure available. These tips are designed so that the flow of acetylene draws atmospheric air into the base of the tip. This results in more oxygen mixing with the acetylene. Another design mixes the gases near the tip end, using a cupped tip end to stabilize the high velocity flame. These special tips are available from various manufacturers under such trade names as "Thruster" (Uniweld), "Swirljet" (Union Carbide), "Swirl Tip" (Turbotorch), and "Ram-jet" (Airco) and are designed for use on the regular air-acetylene handle. They are also available in various sizes for different sizes of flame.

All the high-velocity tips must be operated at 15 psi (103 kPa) flow pressure, which provides a high-heat flame that is usually nonadjustable. The "Thruster"

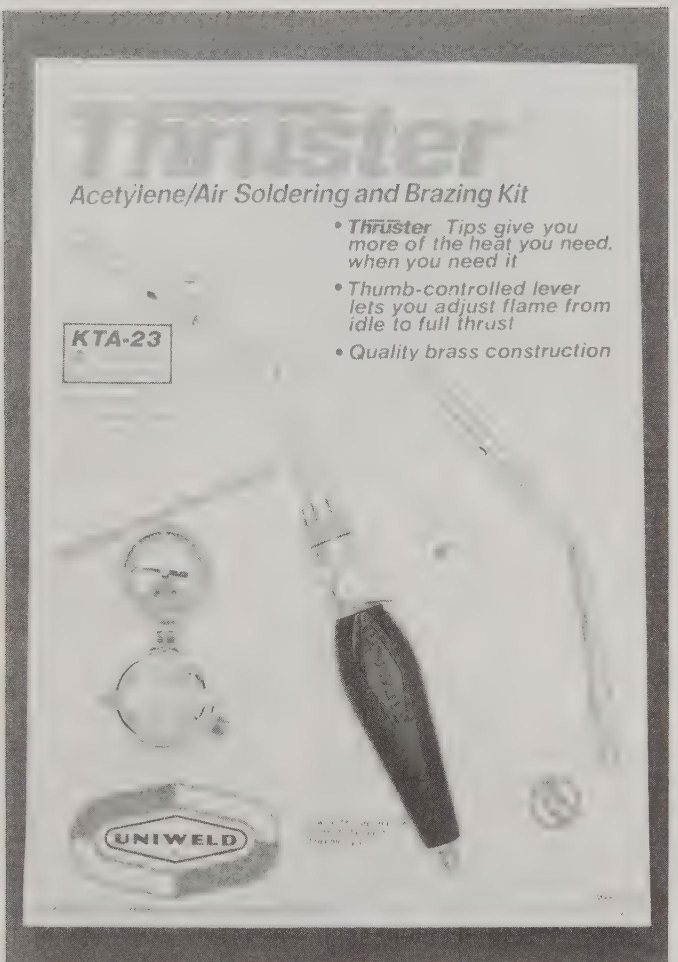


Fig. 6-20. High-velocity tips for air-acetylene torches allow the use of higher temperatures for brazing work. Various designs are available. (Uniweld)

tips by Uniweld are fully adjustable at the torch handle, which gives the operator more variety of flame control. These tips are adjustable from "idle," to soft (medium), to high intensity (full) operation.

Special tip advantages

Some advantages of these special tips are that the flame is pencil-shaped (thin), shorter, and more concentrated for close work. The shorter flame allows soldering or brazing of joints within an inch of walls or woodwork without damaging or discoloring them. It is an all-weather flame: the high velocity allows it to be used in wind, rain, and sub-zero temperatures.

These special tips develop an efficient high heat transfer zone at the tip of the inner cone of the flame. This forms a concentrated heat flow that wraps around the workpiece to heat it evenly and quickly. The flame temperatures in this high heat zone range from 1800°F (982°C) for propane to over 2400°F (1316°C) for MAPP and over 2600°F (1427°C) for acetylene. This gives the user a choice of both tip sizes and gases to meet the heating requirements.

Special tip disadvantages

The major disadvantage of these special tips is that they cannot be used for brazing a connection located near a "heat sink." A ***heat sink*** is any heavy metal device, such as a valve or compressor, that tends to draw heat away from the brazing area. See Fig. 6-21. With these tips, even a moderate-sized heat sink will steal the heat rapidly enough to greatly prolong the brazing process. Also, the supply of acetylene is quickly exhausted because of the higher flow pressures.

It is recommended that all brazing connections be performed with the oxygen-acetylene torch or high-heat-type air/gas tips, reserving soft flame air-acetylene torch tips for soft soldering procedures. The use of air/gas tips where possible saves oxygen for uses requiring higher temperatures, such as cutting, welding, and brazing jobs where heat sinks are involved.

Fig. 6-22 illustrates the tubing sizes appropriate for different high-velocity heat tips when soldering or brazing. Notice the difference in the tubing sizes when

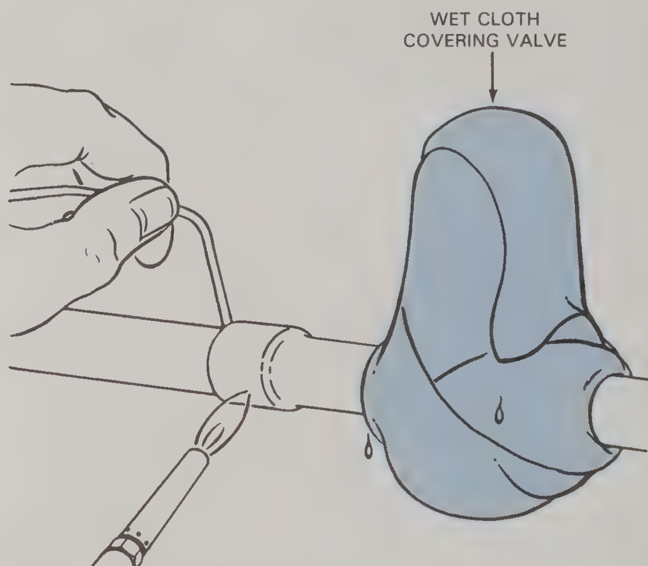


Fig. 6-21. A heavy metal component, such as a valve, will act as a heat sink and draw heat away from the area being brazed. This heat could damage the component. To prevent damage, the valve or other component is sometimes wrapped in wet cloth. (Aeroquip)

TIPS VS. TUBING SIZE		
TIP NO.	SOFT SOLDERING	BRAZING
	COPPER TUBING SIZE	COPPER TUBING SIZE
#3	1/4'' TO 1-1/2''	1/4'' TO 7/8''
#4	1'' TO 2''	5/8'' TO 1-1/8''
#5	1-1/2'' TO 3''	7/8'' TO 1-5/8''
#6	2'' TO 4''	1-1/8'' TO 2-1/8''

Fig. 6-22. This table shows tubing sizes that can be soldered or brazed with each size of high-velocity heat tip.

changing from soldering to brazing with the same size tip. This table does not consider the presence of a possible heat sink.

SUMMARY

Soldering and brazing are both widely used in HVAC work. This chapter provided information on appropriate applications for each process, then explored soldering processes in detail. The different soldering alloy compositions are described, and the importance and proper use of flux is detailed. Safety in working with fuel gases is emphasized.

A major portion of the chapter is devoted to the air-acetylene torch and related equipment. Instructions for use of the torch in soldering and in air-acetylene brazing are given.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Acetylene is used as a ________ gas for soldering and brazing procedures.
2. What is the highest flame temperature obtainable with an acetylene-oxygen mixture?
3. The fusible plug on acetylene cylinders will melt at ________°F (100°C).
4. Why should acetylene cylinders be used in the upright position?
5. The smallest acetylene cylinder is an MC size. What is the next size?
6. Why should the acetylene cylinder valve key or wrench be left on the valve during use?
7. Explain the operating principle of the air-acetylene torch.
8. Acetylene cylinders are pressurized to ________ psi (1724 kPa) at 70°F (________°C).
9. Pressure regulators are used to reduce cylinder pressure to ________ pressure.
10. What color code is used to indicate hoses for acetylene?
11. What is special about threads for acetylene connections?
12. The hottest area of the air-acetylene flame is ________ in. from the ________ of the inner cone.
13. The maximum flame temperature obtainable with the air-acetylene torch is 3600°F (________°C).
14. To distinguish it from brazing, soldering is defined as the joining of metals at temperatures of less than ________°F (450°C).
15. What is the purpose of the soldering flux?
16. Name three types of soldering alloys.
17. The ________ should be melted by heat from the base metal, not the torch flame.
18. What is the flow pressure of the fuel gas for the air-acetylene torch?
19. Aside from the type of thread, how does an acetylene hose connector differ from a connector used for an oxygen hose?
20. The acetylene cylinder valve should never be opened more than ________ to ________ turn.

A portable oxy-acetylene outfit like this one makes it possible to produce good-quality brazed joints when doing installation or repair work on refrigeration or air conditioning systems. (Prest-O-Lite)

Chapter 7

BRAZING AND FLAME-CUTTING

After studying this chapter, you will be able to:
- *Braze copper tubing connections properly and safely.*
- *Select and use cylinders and torches.*
- *Connect and operate oxy-acetylene equipment in a proper and safe manner.*
- *Select appropriate brazing alloys and fluxes.*
- *Describe how to set up, adjust, and use an oxy-acetylene torch for cutting metal.*

NEW WORDS

alloys	multi-flame tip
brazing	neutral flame
backfire	oxidizing flame
cadmium-bearing alloys	oxy-acetylene torch
carburizing flame	preheat flame
cutting oxygen lever	preheat valve
flashback	regulator
hard solders	vertical-down joints
horizontal joints	vertical-up joints

WHAT IS BRAZING?

The processes of brazing and soldering are very similar, except the temperature levels and alloys are different. The same skills are required for both procedures; proper use of the flame is critical. ***Brazing*** is defined as the process of joining metals together at temperatures above 840°F (450°C). In practical terms, brazing is usually accomplished at temperatures of about 1200°F (650°C).

Like soldering, brazing is accomplished by heating the base metals to the required temperature. This must be a temperature higher than the melting point of the filler alloy, Fig. 7-1, but below the melting point of the base metals (For example, copper melts at 1981°F or 1083°C). The melted filler alloy is distributed between the close-fitting base metal pieces by capillary attraction.

For many years, brazing has been the principal method used to assemble heating, air conditioning, and refrigeration equipment. A typical large system may contain hundreds of brazed joints. Brazing permits joining of similar and dissimilar metals, thin and thick sections, and metals having different melting temperatures.

Fig. 7-1. Filler alloys for use in brazing come in a variety of shapes, sizes, and compositions.

Brazing is the preferred procedure for joining tubing in refrigeration systems because the joint is stronger than the base metals, will tolerate vibration without cracking, is leakproof under high pressures, and is noncorrosive. Many local, state, and federal codes *require* brazing on all refrigeration systems.

Some local codes require that licensed technicians make the brazed connections. This license is usually obtained by paying a fee and submitting test samples of properly brazed connections. Good leakproof connections are important, so they are never entrusted to a beginner.

HEAT SOURCES FOR BRAZING

Heating the base metals for brazing is normally done with a torch. Flame temperature is determined by the type of fuel gas used. Oxygen mixed with any fuel gas will give the highest flame temperature possible.

The most versatile heat source for brazing is the oxygen-acetylene torch, most often referred to as an ***oxy-acetylene torch***. It provides the necessary heat ranges to handle all types of joining work, regardless of the materials involved.

Using the oxy-acetylene torch properly and safely is not difficult, nor is achieving good results. Poor results or unsafe conditions are usually due to an improperly adjusted flame and improper pressures. The technician should make every effort to acquire good habits in working with this tool and maintain these habits with every use.

WHERE THE OXY-ACETYLENE PROCESS IS USED

The oxy-acetylene process is used in many fields where metal work is involved. When acetylene is burned with oxygen it produces a flame so hot that it can be used to melt, fuse, or burn any metal.

In the hands of a skilled operator, the oxy-acetylene torch makes it possible to quickly solder, braze, weld, or cut all metals. The intensely hot flame allows you to concentrate a lot of heat in a small area so the brazing process can be performed quickly.

DRESSING FOR SAFETY

An oxy-acetylene torch flame can reach a temperature of almost 6000°F (3316°C); the workpiece can reach temperatures of almost 3000°F (1649°C). The process also can produce flying sparks, molten metal, slag, fumes, and intense light rays, all of which can be harmful to the user or nearby persons.

For your safety, take a practical "head-to-toe" approach to protection. Be sure to provide for hair and head coverage, and wear welding and cutting type goggles with safety-tempered dark lenses (shade 5 is standard). Wear thick gloves and proper shoes. Avoid wearing anything flammable or clothing that has been exposed to flammables (oil, grease, waxes, or solvents). Sparks and molten materials have a way of finding unprotected areas, so be prepared before starting work by being properly protected.

WARNING: The presence of oxygen rapidly increases burning of almost any ignited material, especially oil and grease. Concrete will chip explosively when overheated by the flame.

BRAZING ALLOYS

Brazing alloys usually contain some amount of silver, which has led to the term "silver soldering." This term is incorrect. Silver-bearing solder is an alloy of tin and silver with a melting point of 430°F (221°C). This *soldering* alloy should not be confused with silver-bearing *brazing* alloys that have melting temperatures that range from 1100°F to 1500°F (593°C to 816°C). These brazing alloys are sometimes called ***hard solders***, a term that is in common use, but not universally accepted.

Brazing alloys are available in a variety of forms. The most widely preferred is a 20 in. (50.8 cm) length of 1/8 in. (3 mm) flat rod. The rod is packaged in 1 lb. (.45 kg) or 5 lb. (2.27 kg) tubes. See Fig. 7-2.

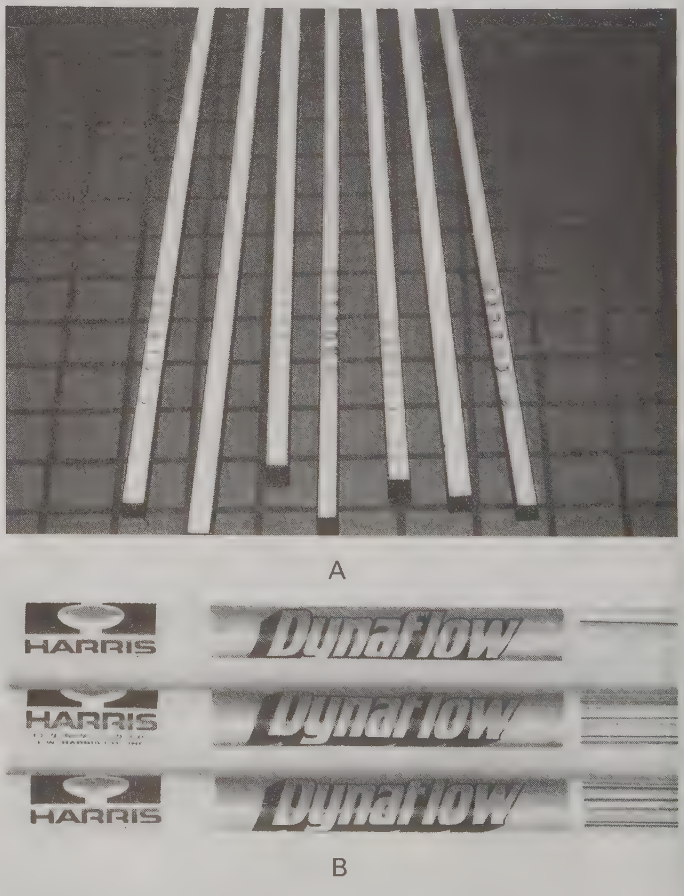


Fig. 7-2. Brazing rods. A–Flat 1/8 in. (3 mm) brazing rod is the form preferred by many technicians. B–Brazing rod is packaged in 1 lb. (.45 kg) tubes, as shown here. Also available are 5 lb. (2.27 kg) tubes. (J. W. Harris Co.)

The term "melting temperature" or *solidus* refers to the temperature at which the alloy starts to melt, while "flow temperature" (*liquidus*) is the temperature at which the alloy becomes a liquid. The difference between the solidus and the liquidus temperatures is called the *plastic range*. Brazing alloys have a relatively wide plastic range, when compared to soldering alloys.

Since they are ***alloys*** composed of different metals with different melting points, the filler metals used in brazing may separate during the heating process. The metal with the lowest melting temperature in the alloy may flow into the joints, leaving the higher-melting-point metals behind. This causes a change in color and strength of the alloy, and makes it difficult to get the remaining alloy to flow. Proper procedure requires the base metals to be heated quickly, to minimize oxidation and to prevent separation of the alloy.

This separation feature that results from brazing alloys' wide plastic range can be an advantage when brazing a loose connection. The higher-melting-point alloys will span the gap. However, the connection will not be as strong if it were made properly. Silver brazing alloys generally melt at 1200°F (649°C) and flow at about 1500°F (816°C), which gives a plastic range of about 300°F (167°C).

ALLOY COMPOSITIONS

Brazing alloys are composed of varying combinations of copper (Cu), silver (Ag), phosphorus (P), and zinc (Zn). The composition of a given brazing alloy determines its use, strength, and cost. Manufacturers have their own numbering system for identification of any particular alloy. However, the American Welding Society (AWS) uses a special numbering system to identify brazing alloys by their composition, regardless of manufacturer. The AWS number can be used to identify and purchase the correct brazing alloy. The AWS number consists of the letter **B** to indicate a brazing alloy, then the chemical abbreviations of the metals used in the alloy, and an identifying number. See Fig. 7-3.

Copper-phosphorus alloy (AWS BCuP-2)

This is a low-cost alloy that is about 93 percent copper and 7 percent phosphorus. This alloy is sometimes called *phos-copper* and is designed to eliminate the need for flux when brazing copper to copper. The phosphorus acts as a deoxidizing agent and flux. When joining copper tubing to a brass or bronze fitting, however, a flux *will* be needed. This alloy definitely *should not* be used for joining copper to steel, since a very brittle joint will result.

When using phos-copper for connecting copper to copper tubing, the surfaces of the connection should be cleaned to bare metal. This alloy has a plastic range of 1185°F to 1500°F (641°C to 816°C).

Copper-phosphorus-silver alloy (AWS BCuP-5)

Many alloys of silver have been developed to provide different melting points, flow properties, strength, and color. Silver brazing is one of the best methods used to connect refrigeration components in a leakproof manner and to provide them with the ability to withstand severe conditions.

An alloy made of 80 percent copper, 5 percent phosphorous, and 15 percent silver (AWS BCuP-5) has been the industry leader for many years. This alloy allows the creation of highly ductile and very strong connections when brazing copper to copper, without using a flux. In addition, with use of a flux, this alloy can braze copper to brass, bronze, or steel. AWS BCuP-5 alloy melts at 1190°F (643°C) and flows at 1500° F (816°C).

Copper-phosphorus-silver alloy (AWS BCuP-4)

Silver-bearing alloys are expensive, and the higher the silver content, the more expensive they become. Alloys with lower silver content have proven economical and have nearly the same characteristics as the 15 percent

CHEMICAL COMPOSITION							
AWS NUMBER	Cu % COPPER	P % PHOSPHORUS	Ag % SILVER	ZN % ZINC	Sn % TIN	TEMPERATURE	
						MELTS	FLOWS
BCuP 2	92.88	7.12				1310	1485
BCuP 3	88.75	6.25	5			1190	1485
BCuP 4	87.00	7.00	6			1190	1480
BCuP 5	80.00	5.00	15			1190	1500
BAg-5	38.00		30	25		1250	1370
BAg-7	22.00		56	17	5	1145	1200
BAg-20	38.00		30	32		1250	1410

Fig. 7-3. The American Welding Society's identification system for brazing alloys assigns a specific letter/number combination to each alloy. This table shows the chemical compositions and the melting and flow (solidus and liquidus) temperatures for some common brazing alloys.

alloys. An example is AWS BCuP-4, which contains 6 percent silver. This alloy was developed to perform nearly as well as the higher-silver-content alloy, and is widely used in the HVAC industry because of its economy. AWS BCuP-5 alloy melts at 1190°F (643°C) and flows at 1480° F (806°C).

ALLOY ADDITIVES

The metals cadmium and zinc are used as additives in brazing alloys that are 35 percent or more silver. These additives provide excellent capillary attraction properties and form excellent brazes on all metals except aluminum and magnesium. They also lower the melting and flow temperatures.

CAUTION: Avoid ***cadmium-bearing alloys*** whenever possible, since cadmium is a toxic metal when molten. It emits highly poisonous cadmium oxide fumes that can cause illness or death. Adequate ventilation is a necessity when using cadmium-bearing alloys.

Cadmium-free alloys that will meet all brazing requirements are available, Fig. 7-4. HVAC technicians should adopt cadmium-free brazing alloys wherever possible to protect their health. The danger of cadmium poisoning is real and the risk is unnecessary. The nontoxic alloys eliminate the danger of cadmium oxide fumes, and can be used on both ferrous and nonferrous metals.

FLUXES FOR BRAZING

Common fluxes used for silver brazing are mixtures of boric acid, borates, fluorides, and fluoroborates. See Fig. 7-5. These chemical powders are formed into a paste by adding water or alcohol. The container usually has a brush for easy application, and if the paste becomes too dry, it may be thinned with water and stirred. The flux must be kept clean to avoid contaminating the joint.

By watching the behavior of the flux, you can determine the temperature at different stages of the brazing process. The flux dries out when the water boils off at 212°F (100°C). When the temperature reaches about 600°F (316°C), the flux will start to bubble and turn milky in color. At about 1100°F (593°C), the flux will turn into a clear liquid. This is the point at which you should apply the filler alloy.

The heating process should be performed as evenly and quickly as possible to reduce oxides. Proper brazing technique requires the process to be performed quickly, which reduces stress on the base metals. Fig. 7-6 lists visual clues for various stages of the heating process.

FUEL GAS CYLINDERS

Oxygen and acetylene cylinders are sized according to the amount of gas in cubic feet the cylinder will hold. These cylinders are also designated by various numbers

Fig. 7-4. Cadmium-free brazing alloys eliminate the problem of poisonous cadmium oxide fumes generated when using a cadmium-bearing filler alloy. (J. W. Harris Co.)

Fig. 7-5. Fluxes for brazing with silver-bearing alloys are packaged in containers of various sizes. Most packages have a built-in brush for application. (J. W. Harris Co.)

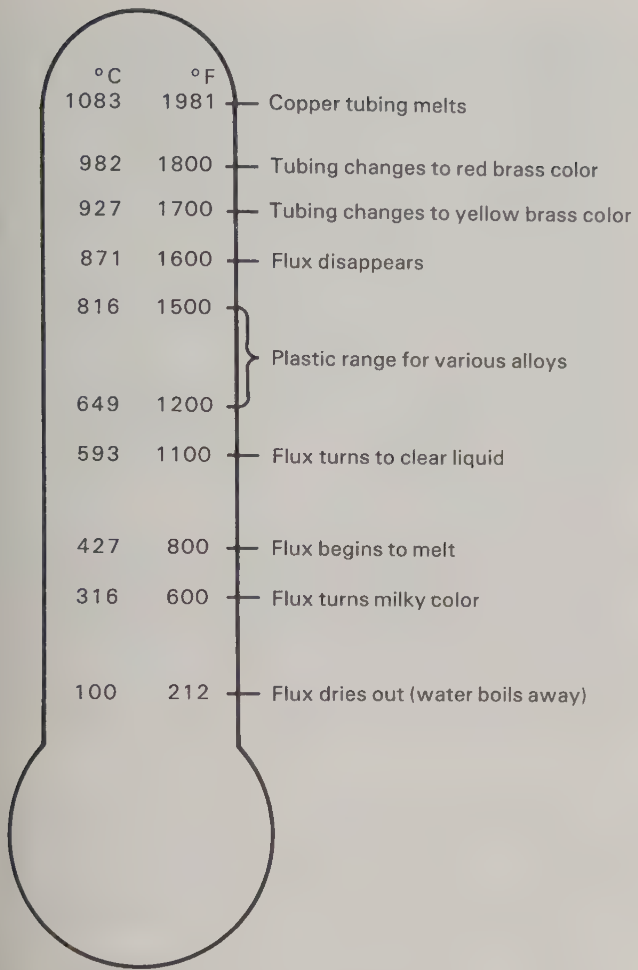


Fig. 7-6. Visual clues to important temperatures involved in the brazing process.

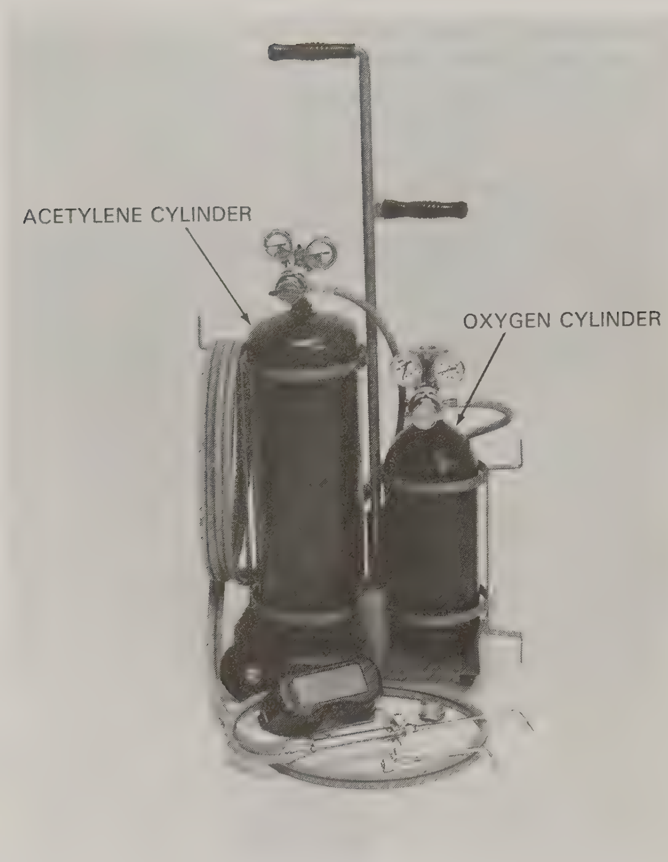


Fig. 7-8. A portable oxy-acetylene outfit with a size ''B'' (40 cu.ft.) acetylene cylinder and a size ''R'' (20 cu.ft.) oxygen cylinder. (Uniweld)

letters of the alphabet to indicate the size. The table in Fig. 7-7 identifies matching sizes of oxygen and acetylene cylinders.

An HVAC service technician seldom uses the large fuel gas cylinders common in welding operations. Technicians usually prefer smaller cylinders that can be easily transported to rooftops, basements, and other locations where heating, ventilation, and air conditioning equipment is installed. See Fig. 7-8. The smaller oxy-acetylene outfits perform the same duty as the larger units, except the operating pressures are different

CYLINDER SIZES FOR MATCHED SYSTEMS		
ACETYLENE		**OXYGEN**
10 cu. ft. (MC)	EQUALS	20 cu. ft. (AA or R-Oxy)
40 cu. ft. (B)	EQUALS	40 cu. ft. (A)
60 cu. ft. (#2)	EQUALS	60 cu. ft. (J)
60 cu. ft. (#2)	ALSO EQUALS	80 cu. ft. (JJ)

Fig. 7-7. This table indicates the different cylinder sizes that can be matched for use in an oxy-acetylene brazing and cutting outfit.

and the supply of oxygen and acetylene does not last as long. To overcome this supply problem, the technician will stock one or two extra cylinders for additional capacity. Carrying stands and small two-wheeled carts are available to accept these smaller cylinders.

An oxy-acetylene outfit that uses the smaller cylinders, regulators, hoses, and torches is called a light duty, or *aircraft* type. This is the unit preferred by many service technicians because of its portability. All the components are matched and have 3/16 in. (Size "A") fittings at the regulator, hoses, and torch handle.

The smaller oxy-acetylene outfits also use smaller brazing and cutting tips. These, in turn, require smaller operating (or flow) pressures. The manufacturer's recommendations should be followed regarding the type of equipment you are operating.

CYLINDER PRESSURES

Oxygen cylinders are charged to a pressure of 2200 psi at 70°F (15 169 kPa at 21°C), but the actual pressure in the cylinder will vary with the temperature. All gases will expand when heated and contract when cooled. If the temperature exceeds 70°F, the pressure in a full cylinder will rise above 2200 psi. A safety relief device is built into oxygen cylinder valves to protect against ex-

plosion due to extremely high pressures. Such pressures might occur if the cylinder were exposed to a fire. For this reason, oxygen cylinders should never be used or stored where they might become overheated.

OXYGEN CYLINDER SAFETY

An oxygen cylinder has a valve designed to operate at high pressures, Fig. 7-9. An iron cap screws down over the valve to protect it during shipment or handling. This cap should always be in place when the cylinder is not in use.

Fig. 7-9. An oxygen cylinder valve is designed to withstand high pressures. It has a double-seating feature that prevents leakage around the stem when the valve is fully opened.

The cylinder valve has a *double seat*, which prevents leakage around the valve stem when the valve is fully opened for operation. To open and close the valve, simple hand pressure is sufficient. A wrench should not be used.

Observe the following precautions when using or handling oxygen cylinders:

- Carefully secure cylinders to keep them from falling over.
- Never store cylinders and equipment in unventilated and confined spaces, in closed vehicles, or near any source of heat or ignition.
- Close cylinder valves securely when not in service or when empty.
- Avoid dangerous pressure unbalance and cylinder contamination by never allowing any cylinder (especially oxygen) to become completely empty. For maximum protection against contamination, install external-type reverse-flow check valves on regulator or torch handle. See Fig. 7-10.
- Never allow oil or grease to come in contact with oxygen cylinder valves. Oxygen reacts violently with oil and grease.
- Do not use a cylinder that has a leaking valve. Carefully move the cylinder outdoors and notify your gas supplier.
- Avoid exposing cylinders to torch flames or electric arcs.
- Never use a cylinder, full or empty, as a roller or support. The cylinder wall could be damaged, resulting in possible rupture or explosion.

OXYGEN REGULATORS

The working (or flow) pressures at the torch tip are considerably lower than the available cylinder pressures. Obviously, a device must be provided to reduce high cylinder pressure to lower working pressure. Also, to maintain a steady and uniform flame, the pressure of the gases reaching the torch tip must not vary (despite steadily decreasing cylinder pressure).

An oxygen ***regulator***, Fig. 7-11, is designed to perform both of these important functions. The regulator is adjustable to permit any flow pressure desired, and will maintain that pressure without further adjustment until the cylinder approaches empty. This point is easily recognized by variations in the flame, or by glancing at the gauge that indicates the cylinder pressure. Always replace a cylinder *before* it becomes empty and unsafe.

The oxygen regulator is attached directly to the oxygen cylinder valve, and contains an outlet for connecting the hose leading to the torch handle. Most regulators have two gauges. One (the high pressure gauge) indicates the pressure in the cylinder; the other (the flow pressure gauge) shows the pressure being supplied to the torch handle.

A pressure-adjusting screw on the front of the regulator is used to set flow (working) pressure. When this screw is turned completely to the left (counterclockwise), the valve is closed and no gas can pass through

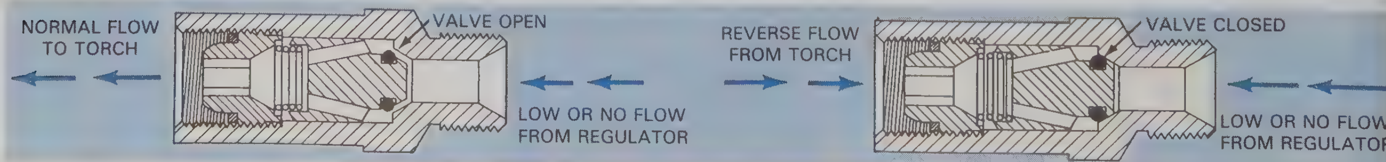


Fig. 7-10. Check valves are designed to prevent contamination of fuel gas cylinders by allowing flow in only one direction. Reverse flow causes the valve to close. (Uniweld)

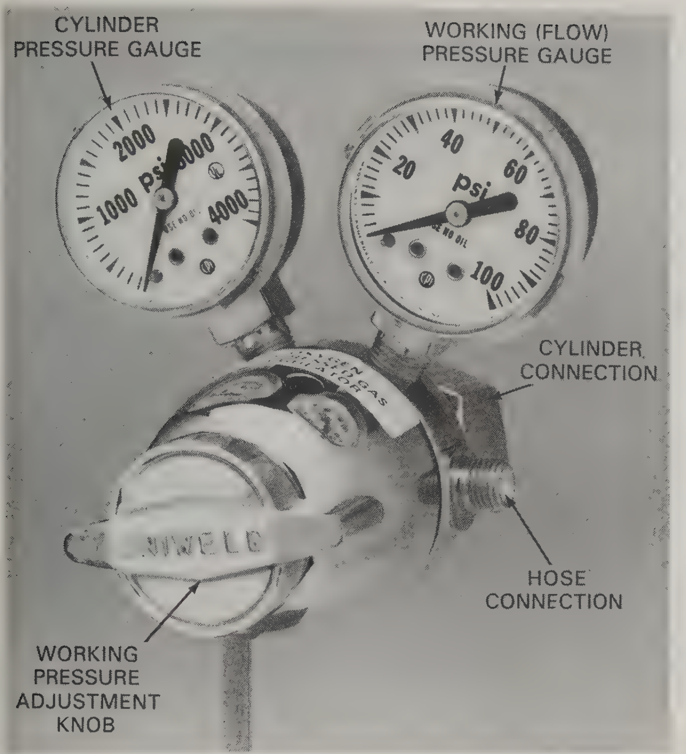


Fig. 7-11. An oxygen regulator is designed to reduce the high-pressure flow of gas from the cylinder to a much lower-pressure flow through the hose and torch. It has separate gauges for the cylinder pressure and the working (flow) pressure. Adjustment of the working pressure is done with a knob on the front of the regulator. (Uniweld)

the regulator. As the screw is turned to the right (clockwise), the regulator opens and permits gas to flow to the torch handle. This is immediately indicated on the flow gauge. Working pressure is changed by simply turning the adjusting screw until the desired flow is registered on the gauge.

Adjusting flow pressure

Pressure cannot be adjusted properly unless the gas is actually flowing. The torch handle valve must be open to permit the gas to be released into the atmosphere. To adjust the flow pressure, you must pretend the torch is lit and operating. After the pressure is adjusted, the torch handle valve is turned off, stopping the flow.

It is necessary to have separate regulators for oxygen and acetylene. These two types of regulators are *not* interchangeable. The regulators and gauges are color-coded: green for oxygen and red for acetylene. They also have special cylinder connections to prevent an acetylene regulator from being connected to an oxygen cylinder, or vice-versa. Always return both regulator screws to the *off* ("backed out," counterclockwise) position when shutting the outfit down.

Regulator safety

The following procedures for using regulators should be followed each time the equipment is set up and used:

- Use a regulator only with the gas for which it is intended. Oxygen regulators must be used only for oxygen service.
- Keep regulators and cylinder connections free of dirt, dust, grease, and oil. Do not use a regulator if it is damaged, or has oil and grease on it.
- Do not crack (slightly open) fuel gas or oxygen cylinders near flame or any source of ignition. Make sure you are in a well-ventilated area, and stand clear of the valve outlet.
- Make sure the threads engage properly when connecting the regulator to the cylinder valve. Tighten with a wrench, but do not use excessive force.
- To shut off the regulator, turn the pressure-adjusting screw counterclockwise until tension is fully released. The regulator should always be shut off when not in use, to avoid gas loss if cylinder or torch valves leak.
- For safety, never stand directly in front of or behind regulators when opening a cylinder valve. Open the valve slowly; open fully only after the high-pressure gauge indicator stops moving. **NOTE:** Open acetylene valves 1/4 to 1/2 turn. Open oxygen valves fully to seal double-seated valve.

OXY-ACETYLENE HOSES

Oxy-acetylene hoses combine specially reinforced rubber and fabric layers to make them strong and flexible. Only hose made especially for welding and cutting should be used. Two lengths of hose, one for oxygen and one for acetylene are necessary to connect the regulators to the torch handle. To prevent confusion, the hoses are color-coded: green for oxygen, and red for acetylene. To further guard against interchanging the hoses, the oxygen fittings (both male and female) have right-handed threads, while the acetylene fittings (male and female) have left-handed threads and a notch cut into the female connector. It is not possible to screw a left-handed nut onto a right-handed fitting.

Twin color-coded hoses, Fig. 7-12, are designed for easier handling, They are furnished in either 12.5, 25, or 50 ft. lengths. The most popular is the 12.5 ft. length with an inside diameter of 3/16 in.

TORCH HANDLE

Nuts on the oxy-acetylene hoses screw onto matching threaded fittings on the base of the torch handle, Fig. 7-13. The oxygen fitting has a right-handed thread and the acetylene fitting has a left-handed thread. These hose connections should be firmly tightened with a wrench. The torch handle also contains two finger-operated valves to adjust the flow of oxygen and acetylene to the gas mixer in the welding tip or cutting attachment.

Oxy-acetylene tips

Various welding tips are available to fit the torch handle, Fig. 7-14. Tips are selected according to the type or size of flame desired. Tip sizes range from 000

(smallest) to 5 (largest). Sizes 0, 2, and 4 are commonly used, with the number 4 being the most preferred. The tip is screwed onto the torch handle by firm hand-tight pressure only. Do not use a wrench. The tip is equipped with special rubber "O" rings to provide a leakproof seal when attached to the torch handle. Overtightening this connection could damage the "O" rings.

Fig. 7-12. Twin color-coded hoses (red for acetylene, green for oxygen) are convenient and less likely to tangle than individual hoses. The notched connector indicates the left-hand threaded acetylene hose. (Uniweld)

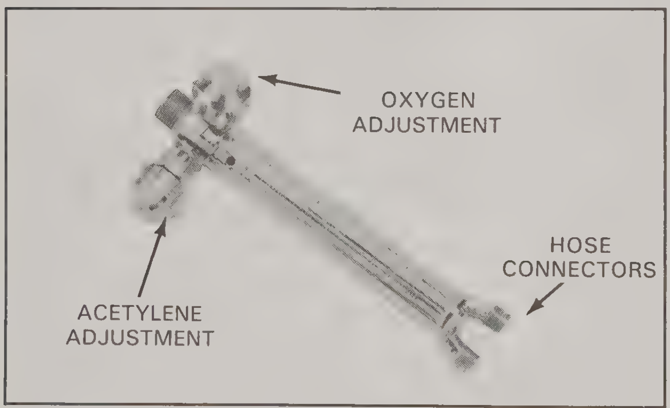


Fig. 7-13. The torch handle has separate adjustment knobs for acetylene and oxygen flow. To prevent mismatching of hoses, oxygen connectors have a right-hand thread; acetylene connectors, a left-hand thread. (Uniweld)

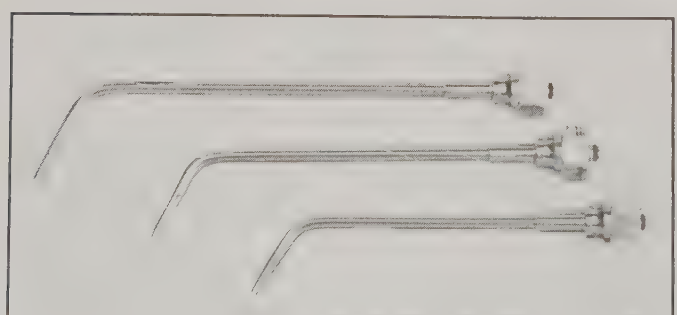


Fig. 7-14. Welding tips come in different sizes. The tip is screwed hand-tight onto the torch handle. (Uniweld)

Welding tips produce a small, concentrated, intensely hot flame. These tips are used to fuse steel together or, by using a filler welding rod, for gas welding. They are frequently used for brazing copper to copper or copper to steel tubing, but care must be exercised to prevent overheating the metal.

Copper melts at 1981°F (1083°C), so it is very easy to melt a hole in the copper tubing. This flame must be moved, or "backed away," from the tubing to prevent overheating and making a hole in the tubing. The hottest part of the flame is at the tip of the inner cone, as shown in Fig. 7-15. The temperature of the workpiece can be controlled by rotating the flame or by pulling the inner cone away from the workpiece.

Selection of the proper tip size is depends entirely upon the size of flame desired. It is not possible to list the proper size tip to use for a given application, because many factors are involved. These factors include the type of metal, thickness of the metal, brazing or welding, and *the skill of the operator*. Trial and error, or some practice with the different tips, will quickly reveal the tip size that produces the desired flame. Thick metals or large copper tubing will require large tips; thin metals or small copper tubing will require smaller tips. Jewelers use the very small tips for delicate work.

Multi-flame tip

Most technicians prefer to braze with a ***multi-flame tip***, Fig. 7-16, which produces several small flames in one tip. The multi-flame tip is very useful because the flame tends to wrap around the tubing. This feature will heat the metal to the desired temperature quickly, but without overheating it.

The flame produced by such a tip is not large or long, but provides much more heat to the workpiece. Such a flame permits a skilled operator to accomplish the brazing process very quickly on any tubing size. The multi-flame tip is the only flame used for **all** types of brazing

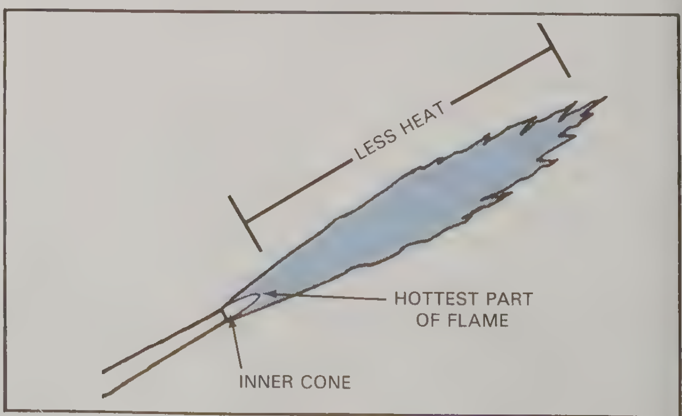
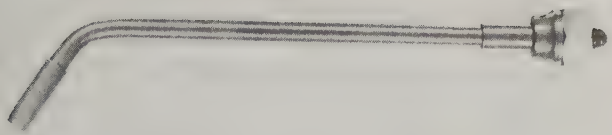


Fig. 7-15. The hottest part of a neutral oxy-acetylene flame is just ahead of the inner cone. Heating of the metal can be controlled by moving the inner cone closer or farther away.



A

B

Fig. 7-16. Multi-flame tip. A–A typical multi-flame tip. (Uniweld) B–The multi-flame tip helps complete brazing jobs rapidly, since the flame tends to wrap around the fitting for rapid, even heating.

jobs. The small size multi-flame tip (#15) will successfully braze 1/8 in. to 3 in. (3 mm to 76 mm) copper tubing with relative ease. This same tip will braze larger tubing, but heating will take longer. The next size tip (#30) is recommended for best results.

The amounts of gases required to operate the multi-flame tip are slightly greater than the amounts used for a single tip, but the difference is not significant. The flow pressures required for the multi-flame tip are the same as those used for a single tip. The holes in the multi-flame tip are very small. In fact, it requires several of these small flames to equal the diameter of the single tip flame. However, the multi-flame tip has the ability to wrap around the tubing and distribute heat more evenly to the workpiece. This important feature speeds the brazing process and helps prevent hot spots.

BACKFIRE AND FLASHBACK

Brazing tips are designed to operate at a certain pressure as recommended by the manufacturer. Tip sizes from 0 to 5 are designed to operate at 5 psig (34 kPa) for both oxygen and acetylene, then adjusted to conform to the desired type of flame. If the flame produced by this procedure is undesirable, the unit should be shut down and the tip size changed. *Do not change flow pressures at the regulator!* Improper operation of the torch tip may cause the flame to go out with a loud cracking sound. This is called a ***backfire.*** A backfire may be caused by touching the flame tip against the workpiece, but the most common cause is from the flow pressures that are too low.

Flashback is a condition in which the flame burns back inside the tip; sometimes, it may extend back through the hoses and to the regulators. This condition is revealed by a shrill hissing or squealing sound. When flashback occurs, the unit should immediately be shut down and allowed to cool before relighting. Flashback is an indication that something is *very wrong*. This condition can be caused by a clogged orifice, but is more commonly caused by incorrect oxygen and acetylene pressures.

Backfire and flashback are usually conditions brought about by the operator attempting to produce a softer flame by choking the flow pressures, either at the handle valves or the regulators. A skilled operator *can* produce a softer flame by adjusting the handle valves, but this procedure has its limits. Such an operator can produce a flame that is suitable for soft soldering, but a less-skilled person should resort to the *air-acetylene* torch for the softer flame.

THE OXY-ACETYLENE FLAME

There are three types of oxy-acetylene flame, as shown in Fig. 7-17. The different flame types are obtained by controlling the amounts of oxygen and acetylene that are supplied to the torch tip.

- A ***carburizing flame*** (also called a "reducing" flame) results from supplying excess acetylene.
- A ***neutral flame*** results from supplying equal amounts of oxygen and acetylene.
- An ***oxidizing flame*** results from supplying an excess amount of oxygen.

An oxidizing flame (too much oxygen) will burn the base metal and produce oxides that interfere with the flow of alloy. A carburizing flame (too much acetylene) results, and will deposit carbon on the base metals, interfering

A

B

C

Fig. 7-17. The three types of oxy-acetylene flame. A–The carburizing flame has excess acetylene. B–The neutral flame has equal amounts of oxygen and acetylene. C–The oxidizing flame has excess oxygen. The neutral flame is best for brazing copper tubing.

with the brazing process. The *neutral* flame, which heats the base metal and neither carburizes nor oxidizes, is the correct flame to use when brazing.

The neutral flame results from using an equal (1-to-1) mixture of oxygen and acetylene. These two gases unite in a way that the oxygen burns up the carbon and hydrogen in the acetylene, so that the flame releases only heat and harmless gases.

FLAME APPEARANCE

The *carburizing* (excess acetylene) flame has three distinct sections:

- A blue inner cone.
- A yellow-white "acetylene feather."
- An outer flame.

The *neutral* (1-to-1) flame has two distinct sections:

- A slightly rounded, blue-white inner cone.
- An outer flame. (The acetylene feather has disappeared into the inner cone.) The *oxidizing* (excess oxygen) flame has two distinct sections:
- A very sharp, pale blue inner cone.
- A shorter, more ragged outer flame than shown by a neutral flame.

The difference between the neutral and oxidizing flames is very small; not much difference is indicated in the inner cone. Care should be taken to remove **only** the acetylene feather when adjusting for a neutral flame. It is better to err on the acetylene side (a slightly carburizing flame) than on the oxygen side (an oxidizing flame).

Although the neutral flame is said to result from supplying equal amounts of the two gases, a *perfectly neutral flame* actually requires **2-1/2** parts oxygen to 1 part acetylene. The regulators area adjusted to provide the 1-to-1 ratio in the inner cone of the flame, and *atmospheric air* provides the other 1-1/2 parts of oxygen needed to complete the combustion process.

PREPARING TO USE THE OXY-ACETYLENE TORCH

The procedure for getting started with the oxy-acetylene torch consists of opening the cylinder valves and adjusting the pressure regulators for the size tip being used. The specific steps used for this procedure are:

1. Inspect the equipment for any damage. Make certain that all valves and regulators are turned off.
2. Open the acetylene cylinder valve slowly, turning it counterclockwise with the proper wrench. Open this valve only 1/4 to 1/2 turn. Leave the wrench on the valve stem so that the cylinder can be turned off quickly in case of an emergency.
3. Open the acetylene valve on the torch handle one full turn. Rotate the adjusting screw on the acetylene regulator slowly clockwise until the flow pressure gauge indicates 5 psi pressure. Close the acetylene torch handle valve, using only finger-tip pressure.
4. Open the oxygen cylinder valve very slowly, turning it counterclockwise until the regulator's cylinder (high-pressure) gauge reaches its maximum setting. When opening the oxygen cylinder valve, *always stand to one side of the regulator* in case of a malfunction. The cylinder valve must be opened slowly to avoid damage to the regulator that could be caused by a sudden surge of about 2200 psi of pressure. After the high-pressure gauge reaches its maximum reading, continue to turn the oxygen cylinder valve until it is fully open. This will back-seat the valve and prevent leakage around the stem.
5. Open the oxygen valve on the torch handle one full turn. Next, turn the oxygen regulator adjusting screw clockwise until the flow pressure gauge indicates a pressure of 5 psi is flowing through the torch. Close the torch handle valve, using only finger-tip pressure (too much pressure on these sensitive valves can damage the ball seat).

LIGHTING THE TORCH

The proper procedures for lighting an oxy-acetylene torch and adjusting to a neutral flame follow.

CAUTION: Whenever you light a torch, be sure the torch tip is pointed away from any source of ignition or any object or person that might be damaged by the flame when it is lit.

1. Crack (open slightly) the acetylene torch handle valve. Use a flint lighter (also called a spark lighter) to ignite the acetylene gas coming out of the torch tip. Hold the flint lighter near the end of the tip, but do not cover the end. A flint lighter is the *only safe* device to use when lighting a torch. Never use matches or a cigarette lighter.
2. Slowly open the acetylene handle valve. When sufficient acetylene is flowing, the flame will stop releasing soot.
3. Slowly open the oxygen valve on the torch handle. As the oxygen is fed into the flame, the inner cone will develop and the acetylene feather will appear. As the amount of oxygen is increased, the acetylene feather will draw back into the inner cone. When the acetylene feather disappears, the inner cone will lose its blurred edge and becomes round and smooth. At this point, you have a *neutral flame*. If more oxygen is added, a sharp pale blue inner cone will appear, indicating an *oxidizing flame*. A neutral or slight carburizing flame is preferred for brazing.

SHUTTING DOWN THE TORCH

If the torch is to be shut down for only a short time, all that is necessary is to cut off the gas flow by closing the torch handle valves, and then lay the torch aside (on a nonflammable surface) until it is needed for use again.

If the unit is not going to be used for a longer period of time, however, the system should be shut down completely by following these steps:

1. Close the hand valves on the torch handle. Turn off the oxygen first to avoid a backfire into the mixer. Quickly shut off the acetylene valve to avoid soot. NOTE: If the acetylene is shut off first, the flame can burn back to the oxygen supply. The acetylene, however, cannot burn back without oxygen. This procedure will also prevent formation of soot inside the mixer and torch that might plug up the passages.
2. Tightly close both *cylinder* valves.
3. Re-open each valve on the torch handle separately to bleed the gases from the hoses and regulators. Continue until regulator gauges read zero.
4. Close the adjusting screw on each regulator by turning it fully counterclockwise. This will help avoid gas loss if cylinder and torch valves leak.
5. Close both valves on the torch handle. Do not overtighten–they should be only finger-tight.
6. Rewind the hose and place unit in safe storage.

MAKING BRAZED CONNECTIONS

Like soldering (as discussed in Chapter 6), brazing is a four-step process:

1. Thoroughly clean the base metal pieces.
2. Apply flux, when appropriate.
3. Heat the base metal pieces evenly to the melting point of the alloy.
4. Apply alloy to the joint.

CLEANING BASE METAL

Dirty metal surfaces will prevent the alloy from traveling into the joint and penetrating the metal. Brazed connections depend upon capillary action to draw the alloy into the joint. When metal surfaces are dirty, they prevent capillary action and keep the alloy from flowing or adhering properly. It is much like applying paint to a dirty wall. The paint will not flow properly, and when the dirt falls off, so does the paint.

The procedure used for cleaning is the same as done for soldering: use sandpaper, emery cloth, wire brush, or other abrasive to remove dirt and oxidation. The cleaned metal surface should be shiny.

USING FLUX

Flux is a chemical compound that is applied to joint surfaces just before brazing. Its purpose is to prevent oxidation of the metal surfaces as they are heated. Flux is normally supplied in paste form and is applied with a small brush. It melts and becomes active during the heating process, absorbing oxides and floating them away from the flowing alloy.

Flux is seldom used in refrigeration and air conditioning system brazing that involves joining *copper to copper*. The flux is eliminated by using an alloy that contains phosphorus, which acts as a fluxing agent.

When brazing dissimilar metals, such as copper to brass or copper to steel, however, the phosphorus-bearing alloy will make a brittle joint. For this reason, a different alloy is used and a flux *is* required.

BRAZING PROCEDURE

Even heating of the base metal pieces is important, so that the alloy will flow equally well on both metal surfaces and will completely fill the joint. Follow this procedure:

1. Adjust the torch for a neutral flame. Flame size should be large enough to envelop as much of the connection as possible.
2. Begin heating the tubing about 1/2 in. to 1 in. (1.25 cm to 2.5 cm) away from the fitting.
3. After the tubing is heated, shift the flame to the fitting. Once the fitting is heated, move the flame steadily back and forth from tubing to fitting. Do not hold the flame in one spot–this causes localized overheating. Continue heating until the assembly reaches the alloy melting temperature.
4. When the assembly reaches the proper temperature, pull the flame back a little. Apply the filler alloy firmly against the tubing at the connection. If the assembly has been properly heated, the alloy will melt and completely penetrate and fill the joint. The alloy will always flow toward the *hottest* area.
5. After the joint has been completed, make one final pass of the flame around the connection to assure proper flow and penetration of the alloy.

TYPES OF JOINTS

There are three general types of brazing connections, identified by the direction that the filler alloy must flow: ***vertical-down joints***, ***vertical-up joints***, and ***horizontal joints***. The following procedures are recommended for making these connections:

Vertical-down joint

In this type of joint, the fitting is *below* the point where the alloy is applied, Fig. 7-18. Bring the entire connection area to brazing temperature quickly and evenly. Heat the tubing first, then the fitting. When brazing temperature is reached, apply a little extra heat to the fitting as the alloy is melting. Since alloy always flows toward the heat, this will help it penetrate into the fitting.

Vertical-up joint

In this type of joint, the fitting is *above* the point where the alloy is applied, Fig. 7-19. Start by heating

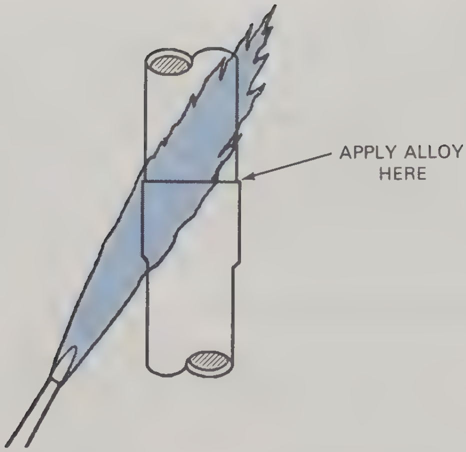


Fig. 7-18. In a vertical-down joint, the alloy is applied above the fitting and is drawn downward into the joint.

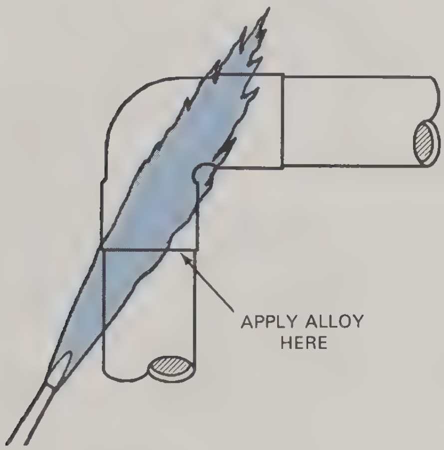


Fig. 7-19. Applying heat to the fitting, after the entire joint area is heated, will help draw the alloy upward into the vertical-up joint.

the tubing, then transfer heat to the fitting. Sweep the flame back and forth from fitting to tubing, all around the joint area. When brazing temperature is reached, keep the flame on the fitting while applying alloy to connection. This heating pattern will draw the alloy up into the joint. Do not overheat the tubing, since this will cause alloy to run downward, rather than being drawn up into the joint.

Horizontal joint

The tubing and the fitting are on the *same level* in this type of joint. Heat both tubing and fitting quickly and evenly. When brazing temperature is reached, apply alloy to the top of joint, as shown in Fig. 7-20. With proper heating, the combination of gravity and capillary action will draw the alloy into the fitting and completely around the tubing. On small-diameter tubing, the flame can be directed at the bottom of the joint while alloy is applied at the top.

When heating assemblies for brazing, extra heat may be needed for sections that have heavier mass or greater

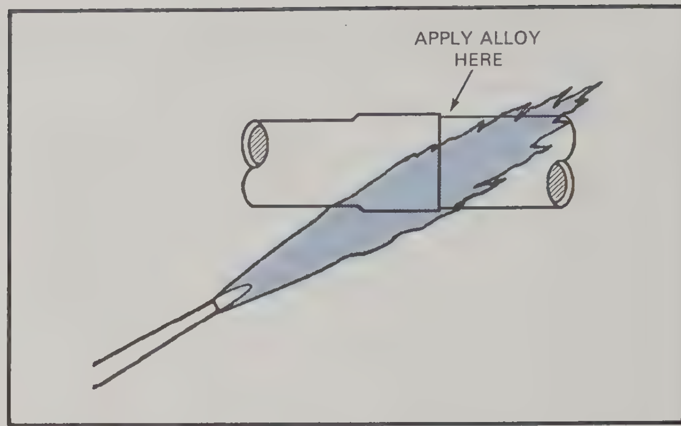


Fig. 7-20. On a horizontal joint, alloy is applied at the top, so that a combination of gravity and capillary action will draw the alloy into the joint.

thickness. The heavier section will heat more slowly. Also, dissimilar metals conduct heat at different rates. For example, copper is a good thermal conductor–it carries heat away more rapidly than steel. **Never** heat base metals to the point where they begin to melt!

TROUBLESHOOTING BRAZED CONNECTIONS

Brazing is a skill that requires practice to develop and maintain. Sometimes, the process fails to produce satisfactory results. The following hints will assist in solving brazing problems.

PROBLEM: Alloy melts and forms fillet, but does not flow into joint.
CAUSES:
- The tubing is hot, but the inside is not up to brazing temperature. (Review heating procedure. Alloy always travels to the heat.)
- Flux destroyed by excessive heat. (Use less heat or apply heavier coating of flux.)

PROBLEM: Alloy balls up, does not flow into joint.
CAUSES:
- Base metal not up to brazing temperature; alloy melted by flame.
- Joint was overheated and destroyed flux.
- Base metal pieces not cleaned.

PROBLEM: Alloy flows away from, not into joint.
CAUSES:
- Fitting not heated to brazing temperature.
- Flame directed away from fitting.

Overcoming heat sink problems

The oxy-acetylene process is especially useful when brazing tubing connections to a valve, compressor, or other heavy metal object. The heavy metal acts as a "heat sink", absorbing applied heat and drawing it away from the brazing area. This heat loss prevents the connection from quickly achieving brazing temperature. Also, the excessive heat may damage the object that acts as a heat sink.

The oxy-acetylene torch makes it possible to overcome heat sink problems. The intense flame heats the brazing area rapidly, permitting the operation to be completed quickly, before much heat can be absorbed by the heat sink.

When the brazing operation involves a heat sink that could be damaged, precautions must be taken. Common practice is to wrap the heat sink with damp rags, Fig. 7-21. Commercial products are also available for application to the heat sink prior to the brazing procedure. Both methods will adequately protect the heat sink from damage, if the brazing process is not prolonged.

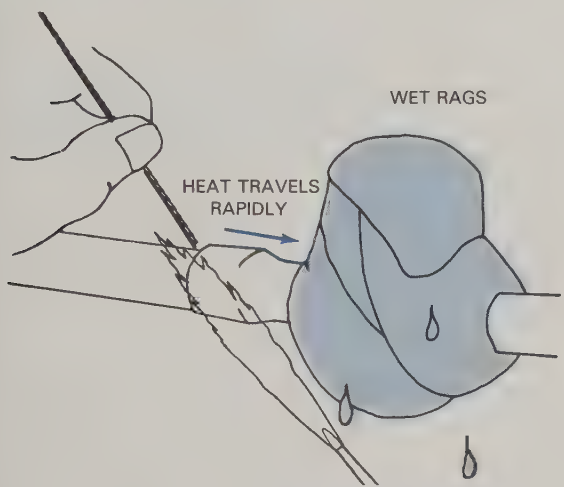


Fig. 7-21. If a valve or other component that acts as a heat sink might be damaged by the heat of a brazing operation, precautions must be taken. Wrapping the heat sink in wet rags is one method used to help keep the temperature down.

OXY-ACETYLENE CUTTING

A special cutting attachment, Fig. 7-22, is used in place of the regular brazing tip when cutting with an oxy-acetylene outfit. The regular brazing tip is removed from the torch handle and replaced by the cutting attachment. Like the brazing tips, the attachment is hand-tightened. No wrench is needed.

The cutting attachment consists of an interchangeable tip, a wheel valve (***preheat valve***) and a lever-actuated valve (***cutting oxygen lever***). Cutting tips are available in a variety of types and sizes to serve special needs. The size #0 "general purpose" cutting tip will cut steel up to 1/2 in. (12.7 mm) in thickness, and is preferred by most technicians.

The tip is connected to the cutting attachment by a threaded nut; use of a wrench is required to make it gas-tight.

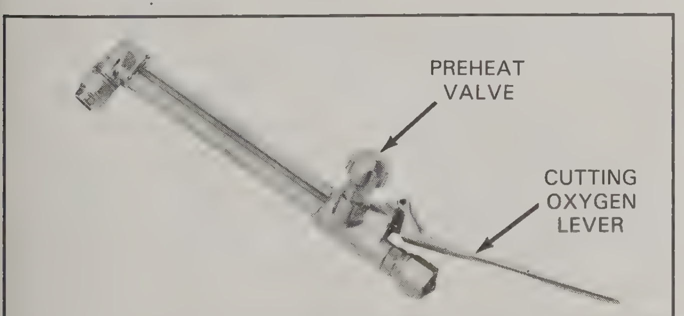


Fig. 7-22. The cutting attachment is threaded to fit on the end of the torch handle (in place of a brazing tip). The preheat valve allows adjustment of the oxygen for the preheat flames. The cutting oxygen lever, when squeezed, permits a strong flow of oxygen through the center hole of the cutting tip. This helps melt or burn away the metal being cut.

CUTTING TORCH OPERATION

The cutting tip, shown in Fig. 7-23, has several small holes surrounding a single (larger) hole in the center. The purpose of the smaller holes is to produce a series of small neutral flames (called the ***preheat flame***). The small flames heat the metal to be cut until it glows bright orange. This occurs at a temperature of about 1625°F (885°C), which is the ignition point of steel.

Once the metal glows orange, the cutting lever is depressed slowly to start a stream of oxygen flowing through the center hole of the cutting tip. This stream of oxygen burns, melts, and blows away the slag and molten metal from the line of the cut. As the torch moves, the preheat flame heats and cleans the metal, while the steady stream of oxygen keeps the burning and melting process going. If the torch is not moved, the cutting action will stop.

PREPARING THE CUTTING TORCH FOR USE

Check the equipment to be certain all parts are in good operating condition and that all valves and regulators are turned off. Wear welding goggles, gloves, and other required protective clothing. Before starting to cut, inspect the area to be certain there are no combustible materials and that there is no chance that the sparks or slag produced by the cutting operation will

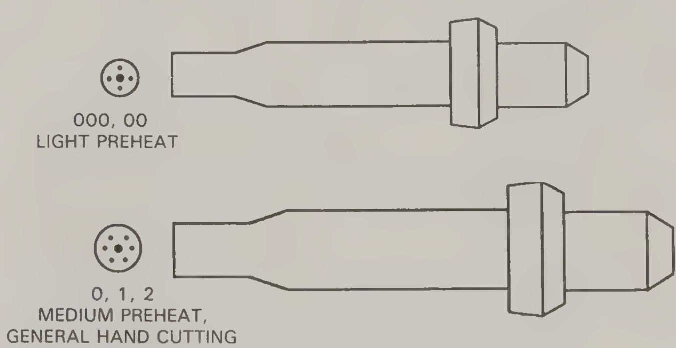


Fig. 7-23. The cutting tip has several small holes surrounding a larger central opening. The small holes are for the preheat flames; the center, for the cutting oxygen jet. Generally, the number of holes for preheat flames increases as the tip size increases.

start a fire. It is good practice to use a shield of some fireproof material to protect your legs and feet from the sparks and slag. It also helps eliminate possible injury when the piece of metal that you cut drops off.

1. Slowly open the acetylene cylinder valve 1/4 to 1/2 turn.
2. Open the acetylene valve on the torch mixing handle 1/2 turn. Adjust the acetylene regulator to permit 5 psig (34 kPa) of flow pressure. Close the torch handle valve finger-tip tight.
3. Slowly open the oxygen cylinder valve all the way to back-seat the valve stem and prevent leakage.
4. Fully open the torch handle oxygen valve. This will transfer control of the oxygen to the preheat valve and the cutting lever.
5. Open the preheat valve. Adjust the oxygen pressure regulator to 20-35 psig (172-241 kPa) for tip sizes 00 or 0 and approximately 25 ft. (7.6m) of hose. The table in Fig. 7-24 relates oxygen pressures to cutting tip sizes.
6. Close the preheat valve. The cutting torch is now ready to light.

CUTTING TIP PRESSURE SETTINGS			
METAL THICKNESS	TIP SIZE	OXYGEN PSIG	ACETYLENE PSIG
1/8''	000	20-25	5
1/4''	00	20-25	5
3/8''	0	25-30	5
1/2''	0	30-35	5
3/4''	1	30-40	5
1''	2	35-50	6

Fig. 7-24. The larger the cutting tip size, the higher the oxygen pressure that should be used, as shown in this table. Also note the relationship of tip size to thickness of the metal being cut.

Lighting the cutting torch

Follow these steps to safely light the oxy-acetylene cutting torch:

1. Open the torch handle acetylene valve about 1/2 turn. Quickly light the flame at the cutting tip with a flint lighter (not matches). Open the valve until a gap appears between the flame and the tip end. Slowly close the valve until the gap is eliminated. This sets the correct acetylene gas flow for the tip size, one that will maintain a stable preheat flame.
2. Slowly open the preheat oxygen valve until the acetylene feathers disappear into sharp blue-white inner cones of the small preheat flames. This establishes a correct neutral flame.
3. Squeeze the cutting oxygen lever while re-adjusting the preheat flames to remove feathers and restore correct flame cones. See Fig. 7-25.

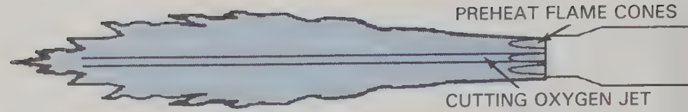


Fig. 7-25. Readjust preheat flame cones while releasing a jet of oxygen by squeezing the cutting oxygen lever.

Using the cutting tip

Hold the torch in your right hand in a way that gives you instant and positive control of the cutting oxygen lever. To steady the torch, close your left hand into a fist, then rest the torch handle on it.

To start the cut, hold the cutting tip straight down facing the surface of the metal. Position the preheat flame about 1/8 in. (3 mm) above the metal's surface. Starting at the edge of the metal to be cut, hold the torch steady until this spot has been heated to a bright orange. Slowly press down on the cutting oxygen lever. As soon as cutting starts, there will be a shower of sparks from the metal. The cutting oxygen lever should be pressed down all the way. Begin moving the torch slowly and steadily along the line of cut. The motion of the torch should be just fast enough so that the cut penetrate completely through the metal, without excessive oxidation or melting.

If the torch is moved too slowly, the preheat flame will tend to melt the edges of the cut, producing a ragged appearance. It also is possible that the metal could fuse together again. If the torch is moved too fast, however, the cutting action will not penetrate all the way through the plate and the cutting will stop. If cutting action should stop, release the cutting oxygen lever, then begin again at the point where the cut stopped.

To avoid flame backfiring (loud popping) or flashback (squealing) inside the attachment, it is important to maintain the correct gas flow to the cutting tip. Backfiring and flashback can also be caused by a plugged, dirty, damaged, or loose cutting tip. If backfiring or flashback occur, shut down the unit and check the tip for plugged holes or seat damage. Clear and clean holes with the proper size tip cleaner, Fig. 7-26. Never use a cutting tip with plugged holes or a damaged seat.

Do not to try to reduce the heat for cutting thin sections by "choking down" or "starving" the preheat flames. Instead, use full correct preheat flames with the tip tilted so they hit the surface at an angle. Move the tip fast enough to prevent overheating and excess melting. Be sure to use the correct small size tip for thin metal to avoid overheating and melting. See the table in Fig. 7-24 for the relationship between metal thickness and tip size.

Shutting down the cutting torch

When you finish cutting, shut down the torch by following the procedure described step by step earlier in this chapter. Remember to shut off the oxygen valve first to avoid backfiring and flashbacks. Also, be sure

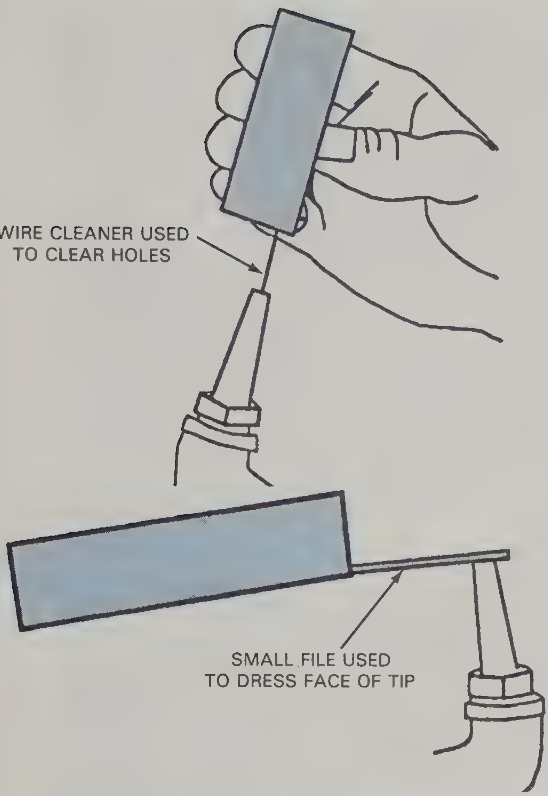


Fig. 7-26. A tip cleaner should be used to clear and clean holes in the cutting tip. Several sizes of tip cleaner may be needed.

to bleed all pressure from hoses and regulators by opening the torch handle valves after cylinder valves have been closed.

SUMMARY

The ability to make good brazed connections is a basic skill requirement for every HVAC technician. Such skills are routinely required for installation and service procedures. This chapter has presented material in a step-by-step procedure that should lead to the development of good brazing skills and safe use of oxy-acetylene torches.

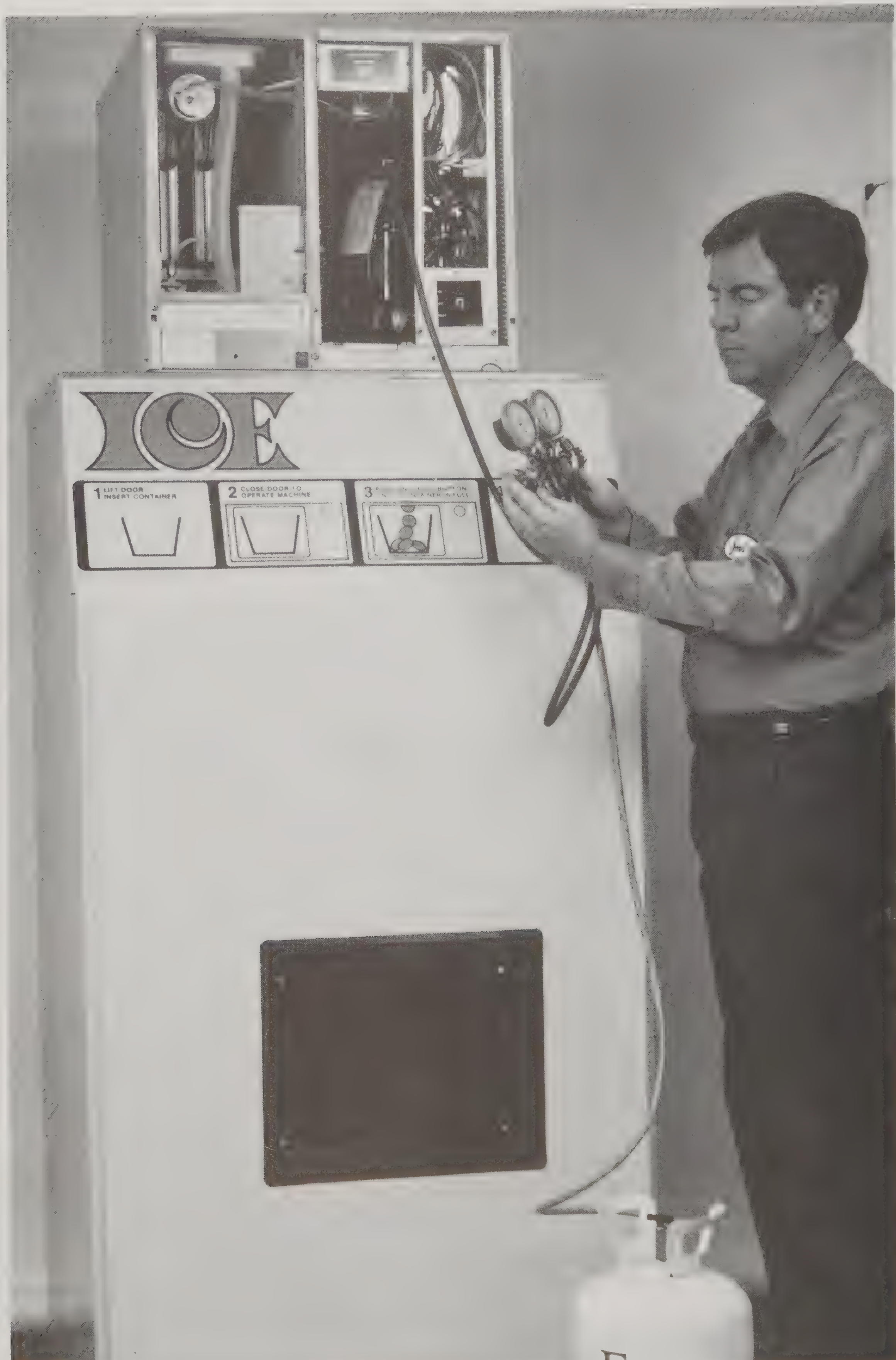
This chapter explained the methods and procedures used for brazing connections. The different alloys and fluxes were also described. Proper use and operation of the oxy-acetylene torch, the recommended torch for performing brazing operations, was explained.

This chapter also explained how to select the proper tips and to operate the valves and regulators to achieve the desired flame. The types of flames and proper methods of applying heat to a connection were covered. Proper use of the cutting torch was described.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Brazing is the process of joining metals together at temperatures above ________ ° F (448°C).
2. In HVAC work, copper is the most common ________ metal.
3. Which of the following is a ferrous metal?
   a. Brass.
   b. Steel.
   c. Aluminum.
   d. Zinc.
4. The copper-phosphorus brazing alloy is good for connecting copper to ________ without need for a flux.
5. The silver-bearing brazing alloys can be used to join copper to steel, but require a ________.
6. Soldering should be performed with the ________-acetylene torch.
7. Brazing should be performed with the ________-acetylene torch.
8. The oxy-acetylene outfit with smaller cylinders that is preferred by many service technicians is called an ________ type.
9. When using oxygen, why should the cylinder valve be fully opened?
10. Oxygen cylinders are charged to a pressure of 2200 psi (________ kPa).
11. What are the flow pressure regulator settings for oxygen and acetylene when using the oxy-acetylene torch for brazing?
12. When brazing with the oxy-acetylene torch, what type of flame should be used?
    a. Carburizing.
    b. Oxidizing.
    c. Neutral.
    d. Reducing.
13. What are at least three reasons why brazing is the preferred procedure for joining tubing on refrigeration systems?
14. Copper will melt at a temperature of ________ °F (________ °C).
15. What is the AWS number for the brazing alloy containing 93% copper and 7% phosphorus?
16. What is the flow pressure regulator setting normally used for oxygen with the oxy-acetylene cutting torch?
17. The wheel valve on the cutting attachment is called the ________ valve.
18. When oxy-acetylene cutting, the preheat flame is used to heat the metal to about ________ °F (885°C).
19. When using the cutting torch, the base metal should be preheated to a ________ color before pressing the oxygen cutting lever.
20. What happens to the preheated metal when the cutting oxygen lever on the torch is squeezed?



Success as a technician in the HVAC field requires a thorough understanding of the thermodynamic principles that are involved in the refrigeration cycle. This technician is recharging a commercial icemaker. (Elf Atochem)

Chapter 8

BASIC THERMODYNAMIC PRINCIPLES

After studying this chapter, you will be able to:
- *Identify the ways in which heat travels.*
- *Describe the process by which a material undergoes a change of state.*
- *Define and distinguish among sensible heat, specific heat, and latent heat.*
- *Explain the significance of the British thermal unit.*
- *Name five different latent heats.*
- *Define saturated conditions, superheat, and subcooling.*
- *Explain and calculate a ton of refrigeration.*

NEW WORDS

absolute zero
boiling point
British thermal unit (Btu)
change of state
conduction
convection
Ice Melting Equivalent (IME)
insulators
kilojoule (kJ)
latent heat
latent heat of condensation
latent heat of freezing
latent heat of melting
latent heat of sublimation
latent heat of vaporization
molecule
physical states
radiation
refrigeration
saturated conditions
saturation point
sensible heat
specific heat
subcooled
superheated vapor
thermodynamics
ton of refrigeration effect

REFRIGERATION AND HEAT MOVEMENT

Most people think of refrigeration as *cold*, or the *cooling process*. However, refrigeration actually deals with the process of **removing heat**. ***Refrigeration*** is the process of removing heat from where it is unwanted and carrying this heat to a place where it can be discarded.

The term *cold* describes a lack of heat, the condition produced by the *removal of heat*. For example, a refrigerator produces "cold" by removing heat from inside the cabinet, then releasing that heat to the outside atmosphere. The refrigeration system simply transfers heat from inside the cabinet to the outside atmosphere, just as you would bail water from a leaking boat and throw that the water back into the lake. See Fig. 8-1.

Heat leaks into the refrigerator constantly through its walls and insulation. It enters with warm air when the door is opened, and still more gets in when warm

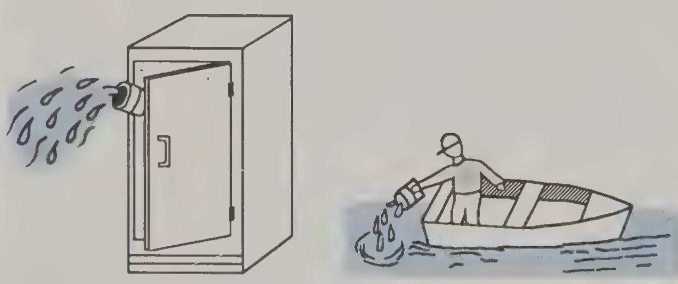


Fig. 8-1. A refrigeration system is similar to bailing out a boat: in bailing, you move water from the inside of the boat to the outside. In a refrigeration system, you move heat from the inside of a house, a refrigerator, or other space to the outside.

foods are placed inside the refrigerator. To accomplish the task of refrigeration, the heat must be removed faster than it enters, just like bailing water from a leaking boat.

THERMODYNAMIC LAWS

Thermodynamics is the science that deals with the mechanical action of heat. There are a number of basic thermodynamic principles, called *laws of thermodynamics.* Two of these laws are very important to the study of refrigeration and air conditioning. Since the HVAC technician works constantly with the controlled movement of heat, an understanding of basic thermodynamic principles is vital.

First Law of Thermodynamics

The First Law of Thermodynamics states that, *energy cannot be created or destroyed, but can be* **converted** *from one form to another.* This law applies to heat and such other forms of energy as: electrical, mechanical, light, chemical, and atomic.

Heat can be generated by converting another form of energy into heat energy. For example, electrical energy is converted to heat energy by such devices as the toaster, electric skillet, hair dryer, water heater, or space heater. Fig. 8-2 illustrates some examples of energy conversion.

Second Law of Thermodynamics

In simplest form, the Second Law of Thermodynamics states that *heat always travels from hot to cold.* Heat energy is always in motion. For example, a spoon placed in hot coffee will absorb heat from the coffee and become hot. How fast heat travels depends upon the temperature difference between two objects: the greater the temperature difference, the faster heat will travel. See Fig. 8-3.

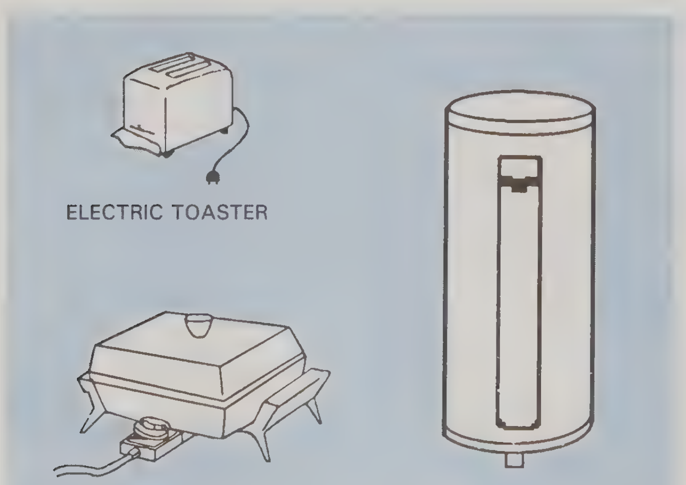


Fig. 8-2. Typical devices used to convert electrical energy to heat energy are the toaster, the skillet, and the water heater.

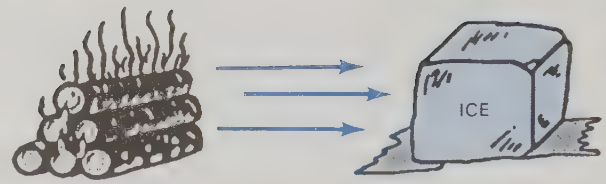


Fig. 8-3. Heat always travels from hot to cold; the greater the temperature difference, the faster the heat transfer will take place.

HOW HEAT TRAVELS

Since refrigeration deals with the movement of heat, it is necessary to know *how* heat travels. There are three basic methods by which heat is transferred from one substance to another: radiation, conduction, and convection. Sometimes, a combination of these methods is used.

Radiation

Radiation is the transfer of heat by waves that are similar to light waves or radio waves. The sun's energy is transferred by means of radiant heat waves, which travel through space in a straight path. Radiant heat waves are absorbed by objects, not the air they pass through. If you have ever moved from the shade into direct sunlight on a hot, sunny day, you have felt the effect of these heat waves. You feel the difference because your body immediately absorbs the radiant heat waves.

Dark-colored materials tend to absorb radiant heat waves; light-colored materials tend to reflect them. Clothing manufacturers use this principle when designing garments for different seasons or climates.

An automobile parked in the hot sun with the windows closed will absorb radiant heat waves, causing the inside of the automobile to become very hot, Fig. 8-4.

Fig. 8-4. Radiant heat is transmitted from a heat source to an object without heating the air through which it passes. The interior of a closed car is quickly heated by the sun on a summer day.

For this reason, never leave a child or pet in a parked car on a sunny day.

Conduction

Conduction is the flow of heat through a substance from one end to the other. An iron skillet is a good example of conduction. If the skillet is placed on a hot fire, heat will travels to the handle until it becomes just as hot as the skillet body.

Heat flow by conduction can take place between two substances or objects if they are touching each other. Conduction is improved by the amount of physical contact involved. Most metals, such as silver, copper, steel, aluminum, and iron, will conduct heat very well. Copper and aluminum are excellent conductors of heat, so these two metals are used extensively in refrigeration systems.

Substances that are poor conductors of heat are called ***insulators***. Examples of insulators are: cork, wood, fiberglass, mineral wool, and polyurethane foams. Insulators cannot totally stop heat flow, but can slow it significantly.

Convection

Convection is the movement of heat by means of a carrier, such as air or water. In a *forced-air* heating system, air can be heated by a furnace and then discharged into the living areas to warm them. The air is then returned to the furnace to be heated again,

Movement of convection currents can be either *natural* or *forced*. Natural convection involves slow-moving currents of air, with lighter warm air rising and heavier cold air falling.. This method was used for older-style furnaces, and is still found in refrigerators.

Forced convection involves using fans or blowers to increase the amount of air movement, Fig. 8-5. This procedure permits the use of smaller and more efficient heat exchangers.

Another method of forced convection uses a liquid to carry heat. The liquid absorbs heat, then is transferred by a circulating pump to another location where the heat is released. A fan forces warm air over liquid-filled tubes, so that the liquid absorbs heat and cools the air. See Fig. 8-6.

MOLECULAR THEORY

All substances or materials are made up of very small particles known as molecules. The ***molecule*** is the smallest physical part into which any substance can be broken down and still have its original identity. For

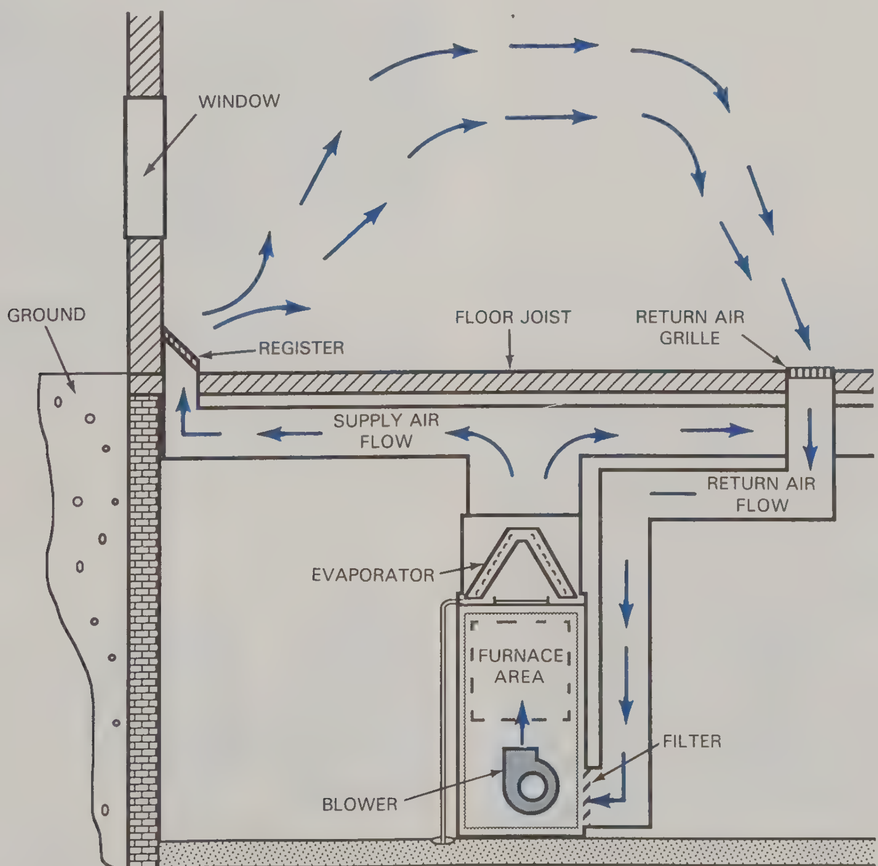


Fig. 8-5. Forced convection transfers heat more efficiently than natural convection. The A-frame evaporator of a central air conditioning system is installed in the plenum of a household furnace. The system uses forced convection to remove heat and distribute the cooled air throughout the living area of a house.

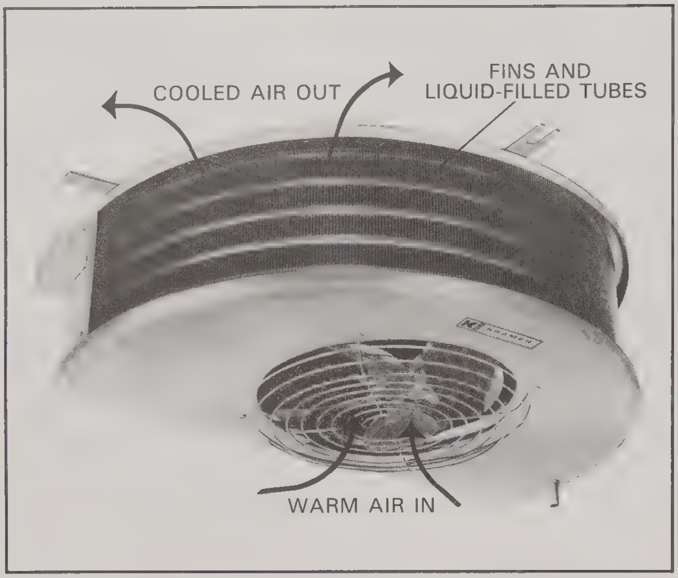


Fig. 8-6. In this forced convection cooling unit, the fan forces warm air through the fins, past tubes filled with liquid refrigerant. The refrigerant absorbs heat, cooling the air.

example, a water molecule (H_2O) consists of two atoms of hydrogen and one atom of oxygen.

Regardless of the type of substance they make up, these tiny molecules are always in rapid motion. As the temperature of a substance increases, the motion of the molecules also increases, Fig. 8-7. As the temperature drops, the molecules slow down. Even in a solid, such as ice or steel, the molecules are moving unless all heat is removed from the substance. If all heat is removed (at ***absolute zero***, -460°F or -273°C), molecular motion will stop completely.

Molecules are like very small building blocks that are arranged in certain patterns to form different substances. In a solid, molecules still move or vibrate, but distances are very limited. The force holding the molecules in place is very strong in a solid. Much heat energy is required to overcome this force and permit the molecules to form a new pattern of movement.

When heat flows from a warmer to a cooler substance, the faster-moving molecules give up some of their energy to the slower-moving ones. As a result, the faster molecules slow down and the slower ones move a little faster.

PHYSICAL STATES

Most substances can exist in three ***physical states***: solid, liquid, or gas. As heat is added or removed, the substance may go through a change of state. Water is the substance commonly used as an example of this process, because it can exist as a solid state (ice) at temperatures below 32°F (0°C), a liquid state (water) at temperatures between 32°F and 212°F (0°C and 100°C), and as a gas (steam) at temperatures of 212°F (100°C) or higher. See Fig. 8-8.

When a substance is changing from one physical state to another, the temperature level *remains constant* (does not change) until all the molecules of the substance are rearranged to the new pattern. This principle is difficult to understand–the question is often asked, "If the temperature doesn't move during a change of state, just where does the heat energy go?" Actually, the energy is being used to shift the molecules into a different pattern.

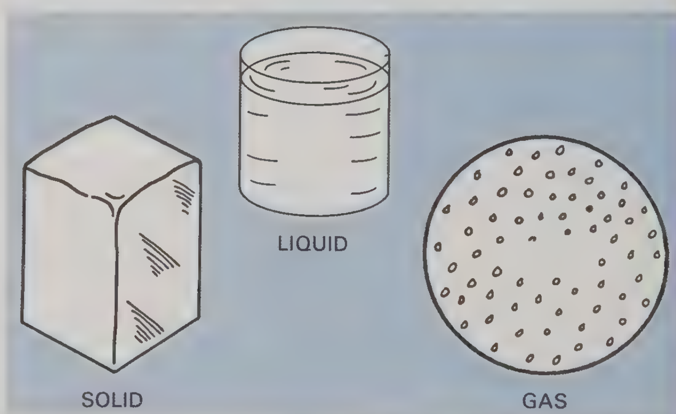


Fig. 8-8. Most substances can exist in any of the three states of matter: solid, liquid, or gas. Water, for example, is a solid below 32 °F (0 °C), a liquid from 32 °F to 212 °F (0 °C to 100 °C), and a gas above 212 °F (100 °C).

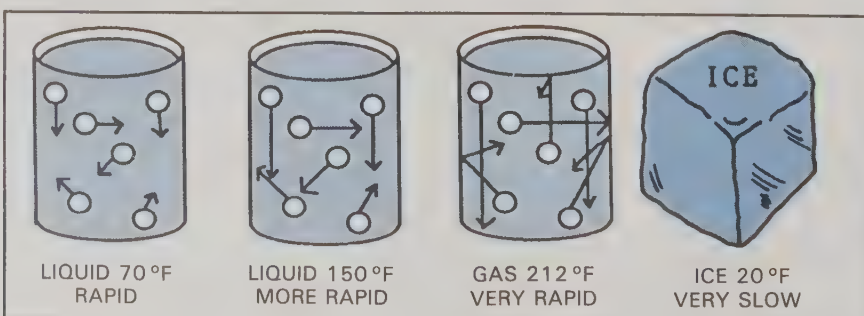


Fig. 8-7. Motion of molecules in a substance speeds up or slows down with the rise or fall of temperature. Molecular motion is slowest in a solid, faster in a liquid, and fastest in a gas.

A liquid allows more movement than a solid, but the molecules' movement is still limited to a specific pattern. When changing from a liquid to a gas (at the ***boiling point***), a large amount of heat energy is needed to shift the molecules and permit them to move in total freedom in all directions as a gas.

CHANGE OF STATE

A ***change of state*** occurs when the temperature and speed of the moving molecules reaches a certain level. At this precise temperature, the molecules will rearrange themselves into a different pattern. The shift in pattern causes the substance to change from a solid to a liquid or from a liquid to a gas. See Fig. 8-9.

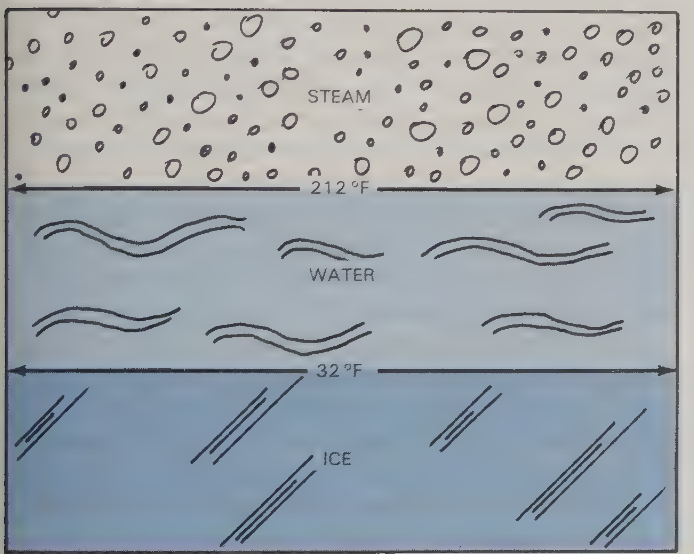


Fig. 8-9. A change of state always occurs at the same temperature for a given substance. For water, the change from solid to liquid comes at 32 °F (0 °C), and the change from a liquid to a gas at 212 °F (100 °C).

This rearrangement of molecules is best illustrated by adding heat to ice that has a temperature of 32°F (0°C). The additional heat will not raise the temperature of the ice, but will provide the energy needed to cause the molecules to shift and rearrange themselves into a liquid (water) pattern.

Once the ice becomes water, adding more heat will cause the water molecules to increase their speed of motion and the temperature will rise. This increase in temperature and speed will continue until the water is heated to the boiling point (212°F or 100°C). Additional heat at this temperature level will provide the energy necessary to cause the molecules to shift their pattern once again, becoming steam.

Of course, the reverse is also true. By *removing* heat from a substance, its temperature will decrease. The molecules will slow down, shifting their pattern to a new physical state (gas to liquid, liquid to solid).

TEMPERATURE AND CHANGE OF STATE

The temperature at which a given substance will change its state is always the *same*. Because the molecules are different for each substance, however, the temperature at which a change of state will occur is *different* for each substance. Water, for example, always boils at 212°F (100°C); ethyl alcohol always boils at 173°F (78°C).

The three states of water (ice, liquid water, and water vapor or steam) are used to explain these basic principles because they are very common and familiar to everyone. These same principles are applied to substances that change state at very high or very low temperatures. Imagine if you can, a substance like liquid ammonia that *boils* at -28° F (-33°C) and *freezes* at -107°F (-77°C)! See Fig. 8-10 for a table of boiling and freezing temperatures for various substances.

Heat energy must be removed to cause a gas to condense back to a liquid. Likewise, heat must be removed to cause a liquid to freeze into a solid. Exactly the same amount of heat energy is involved, regardless of whether heat is being added or removed. It requires the same amount of heat to boil one pound of water as it does to condense one pound of steam. This is true of all substances.

SENSIBLE HEAT

Sensible heat is heat that causes a change in temperature, but not a change of state. When a substance is heated and the temperature rises as a result of the added heat, the added heat is referred to as sensible heat. Likewise, if heat is removed and the temperature of the substance falls, the heat being removed is sensible heat.

BOILING AND FREEZING TEMPERATURES			
BOILING TEMPERATURE (IN °F)		FREEZING TEMPERATURE (IN °F)	
WATER	212	WATER	32
ETHYL ALCOHOL	173	FRUIT & VEG.	30
CHLOROFORM	143	SEAFOOD	28
BUTANE	31	BEEF AND PORK	28
AMMONIA	-28	POULTRY	27
PROPANE	-43	CARBON TET.	-9
CARBON DIOXIDE	-109	LINSEED OIL	-11
ACETYLENE	-118	CHLOROFORM	-81
OXYGEN	-287	AMMONIA	-107
NITROGEN	-320	ACETONE	-139
HYDROGEN	-423	ETHER	-177
HELIUM	-452	ETHYL ALCOHOL	-179

(All the above temperatures are at atmospheric pressure.)

Fig. 8-10. Each substance has specific temperatures at which it changes state (freezes or boils). This table lists temperatures for some common foods and chemical substances.

BRITISH THERMAL UNIT

The *British thermal unit (Btu)* is the basic unit used to measure the *quantity* of heat. A thermometer measures only the temperature of a substance. It cannot measure the amount of heat required to reach a certain temperature.

Many years ago, scientists realized that a standard method to measure quantities of heat was needed. Since water was such a common substance worldwide, they placed a quantity of water that weighed exactly one pound into a container. Next, they measured the precise amount of heat required to raise the temperature of the water one degree Fahrenheit. See Fig. 8-11. The standard they established was accepted by all scientists and is still used today:

One Btu = The amount of heat that is required to raise the temperature of one pound of water by one degree Fahrenheit.

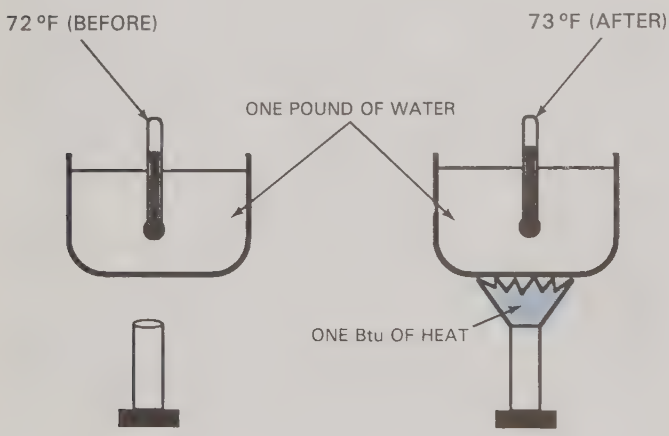


Fig. 8-11. The Btu (British thermal unit) is the standard used to measure quantities of heat. The Btu is the amount of heat needed to raise the temperature of one pound of water by one degree Fahrenheit. In this illustration, the temperature was raised from 72 °F to 73 °F.

If more than one pound of water is involved, it will require one Btu for each pound of water. Likewise, if the temperature is to be raised more than one degree, it will require one Btu for each degree of temperature change. For example:

How many Btu are required to raise the temperature of 10 pounds of water from 72°F to 82°F?

Btu = wt × td (weight × temperature difference)
Btu = 10 × 10
Btu = 100

If a substance is cooled by removing heat, the amount of heat removed is figured the same way. If heat is removed from water, the weight is multiplied by the temperature difference to obtain the number of Btu removed in cooling the water. For example:

How much heat must be removed to cool 50 pounds of water from 75°F to 65°F?

Btu = wt × td
Btu = 50 × 10
Btu = 500

Kilojoule

In the metric system, the unit used to measure quantities of heat is the joule (J). It is, however, a very tiny unit–for practical use in refrigeration work, the ***kilojoule (kJ)*** is used. A kilojoule is 1 000 J. To raise the temperature of one kilogram (kg) of water by one degree Celsius (C), the amount of heat required is 4.187 kJ.

SPECIFIC HEAT

Specific heat is the amount of heat required to raise the temperature of one pound of *any* substance one degree Fahrenheit. This definition is almost the same as that for a Btu, except it considers *all* substances, not just water. The specific heat of water is one Btu, but the amount of heat required (in Btu) to cause a temperature change in other substances will vary with each substance. Each substance requires different amounts of Btu per pound. Scientists have already calculated the specific heats for most substances; these figures are readily available in technical manuals or other references in your library. Fig. 8-12 lists specific heats for some common substances.

Computing Btu requirements

Determining the number of Btu needed to raise the temperature of a substance involves *three* factors:

- The number of pounds of the substance involved.
- The number of degrees the substance's temperature is to be raised.
- The specific heat for the substance.

To find the number of Btu required, multiply the weight times the specific heat per pound times the desired temperature difference.

SPECIFIC HEATS			
SUBSTANCE	SPECIFIC HEAT (LB)	SUBSTANCE	SPECIFIC HEAT (LB)
ACETONE	.514	CHICKEN	3.316
ALCOHOL	.680	CHLOROFORM	2.340
AMMONIA	1.090	COPPER	.095
BACON	1.474	FISH	3.550
BEEF	2.345	ICE	.487
BEER	3.852	IRON	1.373
BENZINE	.412	ORANGES	3.751
BREAD	1.993	PEACHES	3.818
BUTTER	1.373	POPCORN	1.172
CHEESE	2.077	WATER	1.000

Fig. 8-12. Specific heats for a number of foods and other substances are given in this table.

The formula, **Btu = wt × sp ht × tc,** makes it possible to quickly figure quantities of heat. For example:

How many Btu must be removed to cool 50 pounds of water from 75° F to 55° F?

Btu = wt × sp ht × tc
Btu = 50 × 1 × 20
Btu = 50 × 20
Btu = 1,000

How many Btu must be added to 150 pounds of ice to change the temperature from -20°F to 30°F?

Btu = wt × sp ht × tc
Btu = 150 × .487 × 50
Btu = 73.05 × 50
Btu = 3652.50

LATENT HEAT

Latent heat is heat energy that causes a change of state, but no temperature change. During a change of state, the temperature will remain constant until the process of change is completed. Latent heat is sometimes called "hidden" heat, because it does not show on the thermometer. The heat energy is used to rearrange the molecules into a different pattern, and the temperature cannot change until all the molecules have been rearranged.

Each substance has its own temperature/pressure point at which a change of state will occur. For example, under normal atmospheric pressure, ice will melt at 32°F (0°C) or water will freeze at 32°F (0°C). Therefore, at 32°F (0°C), it is possible to have all ice, all water, or a combination of water and ice. See Fig. 8-13. The temperature will remain the same until the change of state is completed. It requires exactly 144 Btu of heat to melt one pound of ice; the same amount of heat must be removed to freeze one pound of water. This is called the latent heat of melting or freezing.

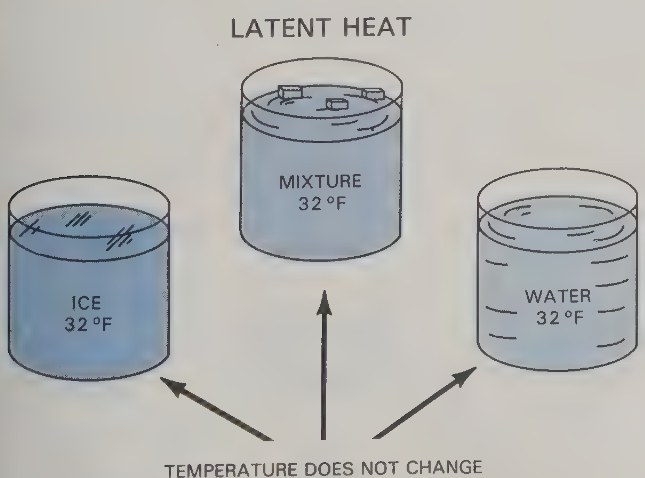


Fig. 8-13. Latent heat causes a change of state, without increasing the temperature of the substance. The temperature will remain constant until the change of state is complete. As shown, while ice is changing state to water, the temperature remains constant at 32 °F (0 °C).

When water is heated, the temperature will stop rising at 212°F (100°C), because the water begins to boil into steam. During this change of state, the temperature will remain at 212°F (100°C) until all the water has turned into steam. It requires 970 Btu to change one pound of water into steam (latent heat of vaporization). If the steam is trapped in a closed container and 970 Btu are removed by cooling the steam, the steam will condense back to water (latent heat of condensation).

There are four latent heats for each substance:

1. The ***latent heat of freezing*** (or fusion) describes the process of changing a liquid to a solid. Heat is removed to accomplish this purpose.
2. The ***latent heat of melting*** describes the process of changing a solid to a liquid. Heat must be added.
3. The ***latent heat of vaporization*** (or evaporation) describes the process of changing a liquid to a vapor. Heat must be added.
4. The ***latent heat of condensation*** describes the process of changing a gas (or vapor) to a liquid. Heat must be removed.

The table in Fig. 8-14 shows latent heat of vaporization/condensation values for some typical refrigerants (water is included as a reference value). Latent heat of vaporization/condensation forms the basis of all refrigeration systems. Refrigerants are the vital working fluids in any refrigeration or air conditioning system. They absorb heat as they change from a liquid to a gas (evaporate). The gas then travels to a place where the heat is removed, causing the gas to return to a liquid state (condense) The refrigerant is then ready for reuse (another cycle).

The Btu computation described above can be used to discover the Btu quantities involved in the heating or cooling process. The following problem is used to illustrate different heat values and the steps required to allow for sensible and latent heats.

PROBLEM: How much heat must be removed to convert 10 pounds of steam at 212°F (100°C) into ice at

LATENT HEAT		
SUBSTANCE	FREEZING OR MELTING BTU/LB.	LATENT HEAT OF VAPORIZATION OR CONDENSATION BTU/LB.
WATER	144	970.4
R-12		68.2
R-22		93.2
R-502		68.96
R-717 (AMMONIA)		565.0

Fig. 8-14. This table provides latent heat of vaporization/condensation values for water and for several common refrigerants. Since the refrigerants are used only in the liquid and gaseous states, no values are provided for the latent heat of freezing/melting.

12°F (-11°C)? This problem is performed in four easy steps, with the specific heat and latent heat values being obtained from the tables in Figs. 8-12 and 8-14.

1. Condense the steam into water. Multiply weight times specific heat times temperature change:
   Btu = wt × sp ht × tc
   Btu = 10 × 970 × 0 (no temperature change–latent heat only))
   Btu = 9,700
2. Lower the temperature of the water from 212°F (100°C) to 32°F (0°C). The temperature change will be 180 degrees (212 - 32 = 180). We must stop at 32°F (0°C), the point where the latent heat of freezing comes into effect.
   Btu = wt × sp ht × tc
   Btu = 10 × 1 × 180 (sensible heat)
   Btu = 1,800
3. Freeze the water into ice.
   Btu = wt × sp ht × tc
   Btu = 10 × 144 × 0 (no temperature change–latent heat only)
   Btu = 1,440
4. Lower the temperature of the ice from 32°F (0°C) to 12°F (-11°C). The temperature change will be 20 degrees of sensible heat (32 - 12 = 20).
   Btu = wt × sp ht × tc
   Btu = 10 × .487 × 20 (sensible heat)
   Btu = 4.87 × 20
   Btu = 97.4

The answers must be added to obtain the total Btu removed to change 10 pounds of steam into ice at 12°F (-11°C).

1. 9700 (condensed steam into water)
2. 1800 (lowered water temperature to 32°F)
3. 1440 (froze the water into ice)
4. 97.4 (lowered the temperature of ice to 12°F)
   TOTAL = 13,037.4 Btu

Imagine the steam, water, and ice enclosed in a copper container that weighs 15 pounds. The copper must then be included in the problem, since its temperature also must be lowered. The copper will remain a solid at these temperatures, so its temperature can be lowered directly to 12° F (-11°C). The temperature change will be 200 degrees (212 - 12 = 200).

Btu = wt × sp ht × tc
Btu = 15 × .095 × 200
Btu = 1.425 × 200
Btu = 285
285 + 13,037.4 = 13,322.4 Btu (new total to be removed).

LATENT HEAT OF SUBLIMATION

Latent heat of sublimation describes the process in which a substance changes directly from a solid to a vapor, without passing through the liquid phase. A common example of this process is "dry ice" or solid carbon dioxide (CO_2). This substance will bypass the liquid state and sublime (go directly from a solid to a gas).

Another example of sublimation is a tray of ice cubes left in the freezer for an extended period of time. The tray may have been full of ice to begin with, but will sublime if not used. When you return from vacation, for example, the ice cube tray may be half full or almost empty.

To review the latent heats and the related state changes:

- **Freezing** (fusion) = liquid to a solid
- **Melting** = solid to a liquid
- **Vaporization** (evaporation) = liquid to a vapor
- **Condensation** = vapor to a liquid
- **Sublimation** = solid to a vapor

SATURATED CONDITION

Saturated conditions is a term often used to refer to the boiling/condensing point of a substance. When the temperature/pressure combination of a substance is such that the substance can *change its state*, the condition is called the ***saturation point***. The boiling/condensing point of a substance is dictated by a specific combination of temperature and pressure.

For water at atmospheric pressure, saturated condition is achieved at 212°F (100°C). See Fig. 8-15. At this temperature/pressure, it is possible to have all water, a mixture of water and steam, or all steam. Whenever a mixture of vapor and liquid exists, it is *saturated* because it is in the process of changing state.

SUPERHEATED VAPOR

The term ***superheated vapor*** describes a gas that has been heated to a temperature that is *above* its boiling point as a liquid at the existing pressure. The air around us is composed of superheated vapors, since the gases that make it up (such as nitrogen, oxygen, and carbon dioxide) all have boiling points well below zero at atmospheric pressure.

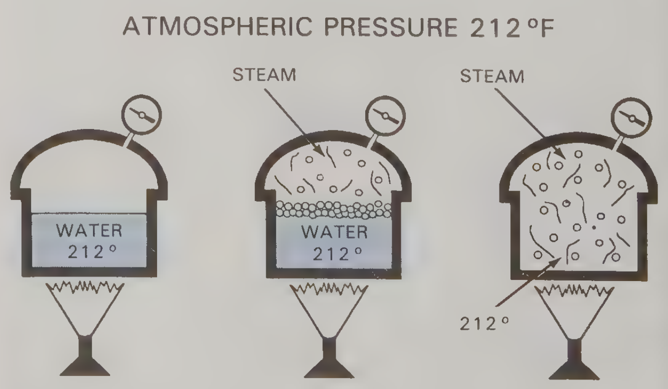


Fig. 8-15. The saturation point of a substance is a specific temperature at a specific pressure. For water, it is 212 °F (100 °C) at atmospheric pressure. Under saturated conditions, the substance can be water, steam, or a mixture of water and steam, all at the same temperature/pressure.

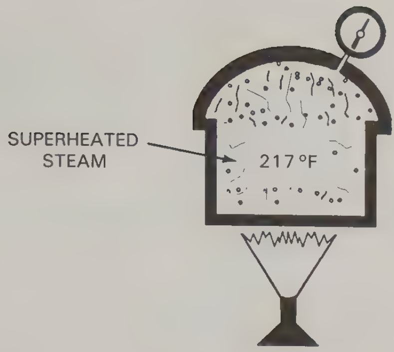


Fig. 8-16. When a substance is superheated, sensible heat has been added after the substance changed state. Superheat can be added to a liquid or a gas. The steam (water vapor) in this example has been superheated 5 °F to a temperature of 217 °F.

Fig. 8-16 shows steam in a superheated condition. Since water vaporizes (becomes steam) at 212°F (100°C), any heat energy added to the vapor will raise its temperature, making it a superheated vapor. The specific heat of steam is .46, so it requires .46 Btu per pound to superheat steam to any temperature above its saturation (boiling) point. Steam at 217° F (103°C) would be superheated by 5°F (217 - 212 = 5).

Vapors and gases

The terms "gas" and "vapor" are often used interchangeably to describe a substance that is in the gaseous state. In a strictly scientific sense, there is a difference between the two terms. In practical, everyday applications in the HVAC field, however, most technicians use the terms interchangeably to describe a substance that is in the gaseous state. This book follows that trade practice.

SUBCOOLED SUBSTANCES

Any substance at a temperature that is *below* its saturation point can be described as ***subcooled.*** While the term is most often applied to a liquid, it also could apply to substances in the solid state.

An example of subcooling is shown in Fig. 8-17: water at 200°F (93°C) is subcooled by 12°F, since the saturation point of water is 212°F (100°C).

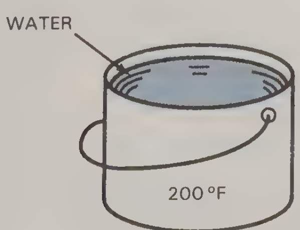


Fig. 8-17. A substance that has a temperature below its saturation point is said to be subcooled. This container of liquid has been subcooled to 200 °F, 12 °F below its saturation point.

TON OF REFRIGERATION EFFECT

Ice (water in a solid state) was the forerunner of all refrigeration systems and is still used today to compare the refrigerating effect of various systems. The unit of measurement is called a *ton* and refers to the ***Ice Melting Equivalent (IME)***–the amount of heat absorbed in melting one ton (2000 lbs.) of ice in exactly 24 hours. See Fig. 8-18.

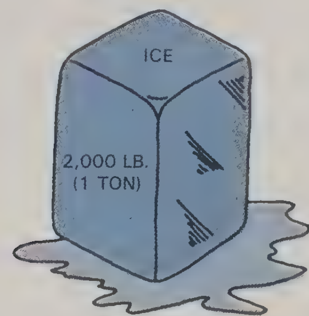


Fig. 8-18. A ton of refrigeration effect is equal to the removal from a block of ice of 288,000 Btu in a 24-hour period (12,000 Btu/hr. or 200 Btu/min.)

By referring to the Latent Heat table in Fig. 8-14, you can see that one pound of ice will absorb 144 Btu when it melts. Therefore, 288,000 Btu will be needed to melt one ton of ice (2000 lbs. × 144 Btu). Any refrigeration system capable of removing 288,000 Btu in 24 hours is, therefore, called a one-ton system.

If you divide 288,000 by 24, you can determine how many Btu are being removed each hour (12,000). Thus, any refrigeration system capable of removing 12,000 Btu per hour (Btu/hr.) is also a one-ton system.

Dividing 12,000 by 60 will identify how many Btu are being removed each minute (200). An absorption rate of 200 Btu/min. is also equivalent to one ***ton of refrigeration effect.***

Therefore, there are three different ways of expressing a Btu removal rate equal to a one-ton system. One of these methods usually appears on the data plate of the system.

- 288,000 Btu/24 hours.
- 12,000 Btu/hr.
- 200 Btu/min.

An air conditioning system rated at three tons would thus have to be capable of removing 36,000 Btu/hr. (or 600 Btu/min.). A half-ton window unit would have the capability of removing 6,000 Btu/hr. (100 Btu/min.) Most systems are rated on a per-hour basis, but you may sometimes see a data plate rating the system in Btu/min.

SUMMARY

The fundamental principles explained in this chapter form the foundation for later chapters that will build upon these principles and put them to practical use.

Heat is a form of energy that can be controlled by using the principles explained in this chapter. Refrigeration and air conditioning systems are designed to move heat from one area to another. To understand how these systems operate, it is first necessary to know what heat is, how heat travels, and how it is measured.

Some of the new words introduced in this chapter are used to explain the conditions of a liquid or vapor when changing its state. These new words will be used frequently in later chapters to quickly explain the condition of the refrigerant as it travels inside the system. The refrigerant acts as a vehicle for transporting heat, and this transportation process involves regular changes of state.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. How does the color of a material affect radiant heat flow?
2. How many "tons" of refrigeration effect can be obtained from a window air conditioner rated at 18,000 Btu/hr.?
3. Name three methods by which heat travels.
4. Define the term "cold?"
5. What is the First Law of Thermodynamics?
6. What is the Second Law of Thermodynamics?
7. Name the three physical states of matter.
8. Define sensible heat.
9. What is latent heat?
10. A British thermal unit is the amount of __________ that will raise the temperature of one __________ of water by one degree __________?
11. The specific heat of copper is __________.
12. Name the five latent heats.
13. What does the term "saturated" mean?
14. What is superheat?
15. When a substance is at a temperature lower than its saturation point, it is said to be __________.
16. One ton of refrigeration effect is equal to how many Btu/hr.?
17. True or false? At a temperature of 32°F (0°C), the material in a container can be all water, all ice, or a combination of water and ice.
18. Give an example of sublimation.
19. Heat always travels from __________ to __________.
20. What is specific heat?

Chapter 9

TEMPERATURE AND PRESSURE

After studying this chapter, you will be able to:
- *Identify four different thermometer scales.*
- *Discuss the importance of Fahrenheit and Celsius absolute temperatures.*
- *Describe atmospheric pressure and how pressures are measured and read.*
- *Describe vacuum measurement and the use of the compound gauge.*
- *Explain and apply Boyle's Law and Charles's Law.*

NEW WORDS

absolute pressure	gauge pressure
absolute zero	hydrargyrum
ambient temperature	in. Hg.
atmospheric pressure	Kelvin scale
boiling point	mercury barometer
Boyle's Law	partial vacuum
Celsius scale	perfect vacuum
centigrade	psia
Charles's Law	psig
compound gauge	Rankine scale
cryogenics	refrigerant
Dalton's Law	temperature
Fahrenheit scale	variable

TEMPERATURE AND PRESSURE

The information on temperature and pressure given in this chapter is the foundation for understanding all refrigeration and air conditioning systems. These systems contain a ***refrigerant*** that readily changes from a liquid to a gas, then is condensed back to a liquid for recirculation. The effect of temperature and pressure changes on the refrigerant is controlled and predictable. A thorough understanding of the principles presented in this chapter is required to help the technician deal with constant temperature and pressure changes within the system.

WHAT IS TEMPERATURE?

Temperature does not reveal the *quantity* of heat in a substance. It merely tells you the intensity, or heat *level* (how hot or cold) a substance is. In the molecular theory of heat, temperature indicates the speed of motion of a single molecule. Temperature specifies how hot a substance is, but does not indicate how many Btu were needed to reach that temperature level.

For example, consider two containers of water over identical heat sources. In the first container, there is one gallon of water; in the second, five gallons. See Fig. 9-1.

If the same *amount* of heat is applied to each container, the temperature level of the water in the first container will rise more quickly than the level in the second container. If the temperature level of the water in both containers is raised to 180°F (82°C), the second container would require many more Btus of heat than the first to achieve the same temperature level.

MEASURING TEMPERATURE

Temperature, or heat level, is measured by a device called a thermometer. Thermometers are used only for measuring sensible heat, and usually consist of a glass tube calibrated in *degrees*. Inside the tube is a liquid, such as mercury or colored alcohol, that will expand or contract at a known rate with changes in temperature.

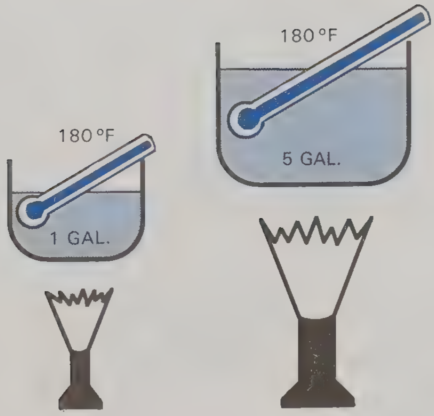


Fig. 9-1. To reach the same temperature, the larger quantity of water in the container at right would require many more Btus of heat than the smaller quantity in the container at left.

This will cause the liquid to rise or fall within the tube, where its level can be compared to the degree marks.

In the United States, temperature is usually measured in degrees Fahrenheit, but in other parts of the world, and for scientific work, the Celsius scale is used.

FAHRENHEIT SCALE

In the year 1714, the German scientist Gabriel Fahrenheit (1686-1736) became the first person to use mercury as the liquid in a thermometer. Mercury allowed more accurate measurement of temperature changes than other liquids used before. In order to calibrate his thermometer, Fahrenheit chose the freezing point of a mixture of salt and water as the *zero* point. Ordinary water freezes at 32 degrees on the ***Fahrenheit scale***, and boils at 212 degrees. As shown in Fig. 9-2, there are exactly 180 divisions (*degrees*) between the freezing point of water and the boiling point of water (212 - 32 = 180). Any temperature that occurs below zero is expressed as a negative or "minus." For example, a temperature of 10 degrees below zero is written as -10°F.

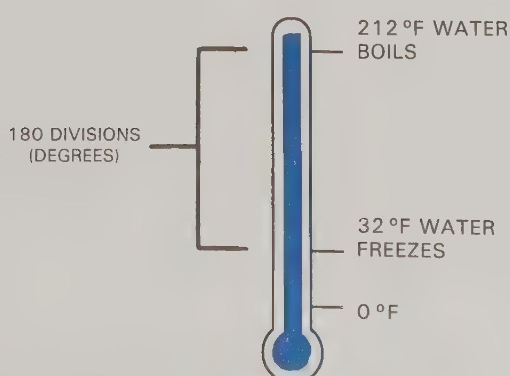


Fig. 9-2. The Fahrenheit temperature scale has 180 divisions between the freezing point of water and the boiling point of water. Fahrenheit set zero at the point where a mixture of salt and water froze.

CELSIUS SCALE

The Swedish astronomer Anders Celsius (1701-1744) believed the Fahrenheit scale was impractical for laboratory use, because its 180 divisions between the freezing and boiling points of water required troublesome mathematical calculations. To overcome this problem, Celsius developed his own scale in 1742. He called it the ***centigrade*** ("hundred steps") scale, because it had exactly 100 divisions between the freezing (0°) and boiling (100°) points of water. See Fig. 9-3. This new scale was quickly adopted by other scientists. Today, it is used by most countries of the world. Since 1948, the centigrade scale has been officially known as the ***Celsius scale***.

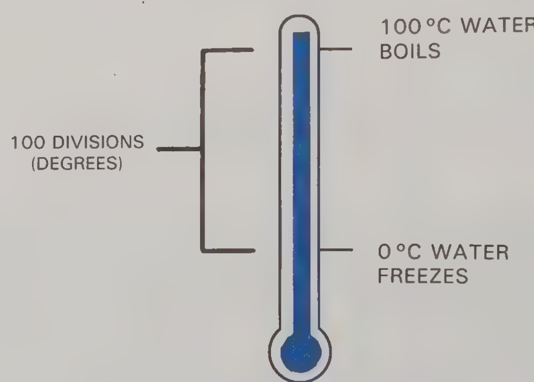


Fig. 9-3. The Celsius temperature scale has 100 divisions between the freezing point of water and the boiling point of water. This makes it easier to use, especially in scientific work.

Absolute zero

When Fahrenheit devised his scale, he set the zero point at the temperature where salt water froze, since this was the lowest temperature he could achieve in the laboratory.

The *lowest possible* temperature, ***absolute zero***, is far below -32°F. Scientists have established that heat is always present until a temperature of -460°F (-273°C) is achieved. This temperature is the lowest possible temperature because *all* heat has been removed. It is, therefore, called absolute zero.

At this temperature, all molecular motion stops because there is no heat in the substance. By comparison with absolute zero, the coldest weather we might experience on Earth is quite warm. Atmospheric air with a temperature of zero degrees Fahrenheit would contain many Btus of heat.

RANKINE AND KELVIN SCALES

For some types of scientific work, the use of *absolute temperature scales*–scales with no negative numbers–were a great convenience. In the mid-1800s, two Scots scientists, William Rankine and William Thomson (Lord Kelvin), developed two different approaches to the absolute temperature scale.

In the ***Rankine scale***, Fahrenheit divisions are used. Absolute zero is 0°R, the freezing point of water is 492°R, and the boiling point of water is 672°R. The Rankine scale is also known as the Fahrenheit Absolute (F_A) scale.

Kelvin's approach was identical, but he preferred use of the Celsius scale. Absolute zero is 0°K, water freezes at 273°K, and water boils at 373°K. The ***Kelvin scale***, which he called the Celsius Absolute (C_A) scale, has achieved wide use by scientists. Fig. 9-4 is a side-by-side comparison of the four temperature scales.

Cryogenics

Cryogenic refrigeration systems (those capable of producing temperatures below -250°F) are used in laboratories to perform various scientific experiments. For instance, at absolute zero all substances (even rubber) become perfect conductors of electricity. Research in the cryogenic temperature range has resulted in the discovery of materials that are superconducting (exhibiting no electrical resistance) at temperatures well above absolute zero.

AMBIENT TEMPERATURE

The term ***ambient temperature*** is used frequently in the refrigeration field. It simply refers to the temperature surrounding the object under discussion, usually a motor or condenser. Ambient temperatures can have a great influence on the operating conditions of a system, or part of a system. For example, a motor may be rated to give maximum efficiency at any temperature that does not exceed 72°F (40°C) above ambient.

Many times, a refrigeration system will have components located outside the building that are connected to other components located on the inside. The ambient temperature of the inside components is controlled, and thus remains relatively constant. However, the components located outside are exposed to all types of weather conditions, Fig. 9-5. These ambient temperature conditions can be rather extreme, compared to those experienced by indoor components. The word ambient makes communication easier when referring to the temperature conditions surrounding the object under discussion.

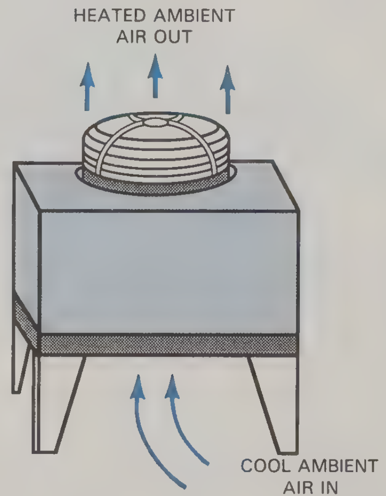


Fig. 9-5. Ambient temperatures refer to the temperature condition surrounding an object being discussed. Ambient cool air is drawn through the outdoor condenser of an air conditioning system. As the moving air absorbs heat from the condenser coils, it becomes *heated* ambient air.

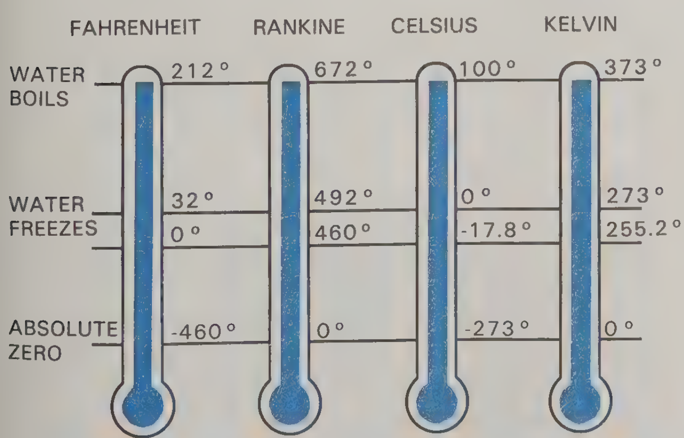


Fig. 9-4. A comparison of four temperature scales. Both the Rankine and Kelvin scales use absolute zero as their zero point. The Rankine scale is based upon Fahrenheit degree divisions; Kelvin on Celsius divisions.

ATMOSPHERIC PRESSURE

Our planet is surrounded by a gaseous atmosphere that consists of about 78% nitrogen and 21% oxygen (the remaining 1% is composed of rare gases). The atmosphere extends approximately 50 miles above the earth's surface and is held in place by the force of gravity. The gases that make up the atmosphere are composed of tiny molecules traveling in all directions. Even though they are very small, these molecules are not weightless. The weight of the molecules exerts a downward force, known as ***atmospheric pressure***, upon the earth's surface. This pressure is greatest at sea level, and is generally considered to be 14.7 pounds per square inch (101.3 kilopascals). At higher altitudes, such as at the top of a mountain, the atmospheric layer is much thinner and exerts less pressure. See Fig. 9-6.

Because the atmosphere is composed of a mixture of gases, pressure is exerted in all directions. At sea level, anyone or anything exposed to the atmosphere will have 14.7 pounds of pressure exerted against every square inch of surface area.

ATMOSPHERIC PRESSURE AND BOILING POINT

Atmospheric pressure has a direct influence on the ***boiling point*** of water and other liquids: if the amount of pressure on a liquid is changed, the boiling point will

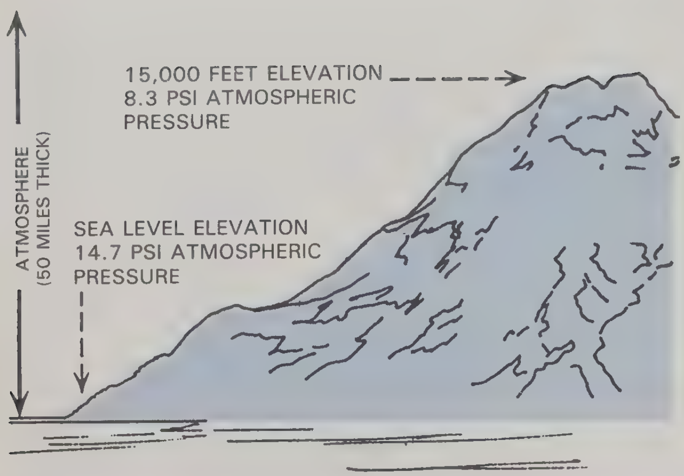


Fig. 9-6. Atmospheric pressure (14.7 psi at sea level) is a result of the weight of gas molecules in the miles-thick layer of air surrounding the Earth. At higher levels, the pressure is lower because the blanket of air is thinner (and thus weighs less).

also change. At sea level, where atmospheric pressure is 14.7 psi (101.3 kPa), water boils at 212° F (100°C). At the summit of a mountain 15,000 feet high, however, atmospheric pressure is only 8.32 psi (57.3 kPa) and water boils at 184° F (84°C).

When a liquid substance, such as water, reaches its boiling point (saturation point), additional heat causes a change of state. The temperature of the substance remains constant until the change is completed. To illustrate this, consider an open pan of water over a flame on the kitchen range, Fig. 9-7. In this example, the water is at atmospheric pressure, so it will boil when a temperature of 212°F (100°C) is reached. The water cannot get hotter, *regardless of the amount of heat applied.* The water will only boil at a faster rate; the temperature will remain constant until the change of state is completed and all the liquid is changed to a gas.

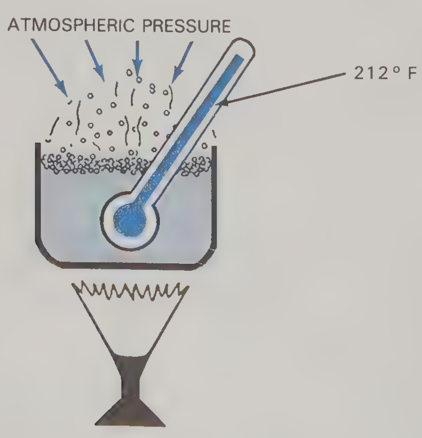
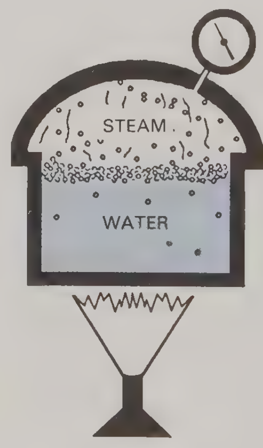


Fig. 9-7. At normal atmospheric pressure (14.7 psi), water boils at 212 °F. The water will remain at that temperature until the state change is completed (it all turns to steam). Adding heat will merely make it boil faster.

Atmospheric pressure creates a surface tension on top of the water. This opposes the escape of water molecules that are trying to break through the surface and become a gas. As the temperature of the water increases, the speed of the constantly moving water molecules also increases. If the speed of the water molecules increases to the point where surface tension can no longer keep them from escaping, the boiling point has been reached. There is now a mass escape of molecules changing state from liquid to gas (water to steam).

The pressure cooker, Fig. 9-8, was invented to permit water to be heated to temperatures above its normal boiling point without changing state. Placing a sealed lid on top of the kettle traps the molecules of water vapor in the small space between the lid and the surface of the boiling water. As the space becomes crowded with escaped water molecules, the pressure will increase. This increased pressure on the surface of the water will prevent the escape of additional molecules. In effect, the water stops boiling. To continue the process of changing the water's state from liquid to gas, the temperature of the water must be raised to overcome the increased surface pressure. Thus, as the surface pressure is increased, the boiling point is also increased.



PRESSURE ABOVE ATMOSPHERIC	BOILING POINT
5 PSI	228 °F
10 PSI	244 °F
15 PSI	250 °F
35 PSI	281 °F
85 PSI	328 °F

Fig. 9-8. By enclosing a liquid and increasing pressure (as in this "pressure cooker"), the boiling point of the liquid can be raised. Some examples of boiling point increases are shown.

VACUUM

While an increase in surface pressure results in an increase in the boiling point, the *reverse* is also true: reducing surface pressure will reduce the boiling point. Any pressure less than atmospheric is called a ***partial vacuum.*** When *all* atmospheric pressure is removed, it is called a ***perfect vacuum.*** If you were able to achieve such a perfect vacuum, water would boil at 40°F (4°C). See Fig. 9-9.

A good understanding of vacuum principles is a *must* for the HVAC technician.

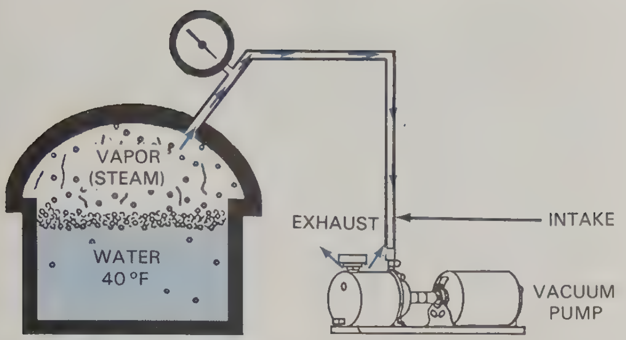


Fig. 9-9. Reducing atmospheric pressure on a liquid (creating a partial or perfect vacuum) lowers the temperature at which it will boil. In this example, a vacuum pump is used to remove all atmospheric pressure from the water in the closed container. In such a perfect vacuum, water will boil at 40 °F.

Measuring vacuum

The most common method used to measure atmospheric pressure is the ***mercury barometer.*** As shown in Fig. 9-10, this device consists of a hollow glass tube about 34 inches high, sealed on one end and open at the other. The glass tube is filled with mercury, turned upside down, and the open end placed in a dish half-filled with mercury.

The level of the mercury in the glass tube will correspond to the atmospheric pressure being exerted on the mercury in the open dish. The normal atmospheric pressure of 14.7 psi (101.3 kPa) exerted on the exposed mercury in the dish will cause a 29.92 inch column of mercury to be forced up into the tube. From this, it can be seen that every pound of atmospheric pressure is equal to 2.035 inches of mercury in the column.

Mercury was once referred to as "quicksilver" or liquid silver. In Latin, the term "liquid silver" is ***hydrargyrum***. The abbreviation of hydrargyrum, **Hg**, is the chemical symbol for mercury. To indicate inches of mercury in vacuum measurements, the abbreviation ***in. Hg.*** is used. To illustrate, a partial vacuum of 25 inches of mercury would be written as 25 in. Hg.

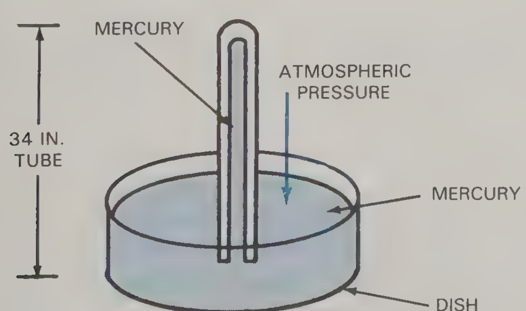


Fig. 9-10. A mercury barometer. Atmospheric pressure on the mercury in the open dish supports a column of mercury inside the tube. By marking the tube in increments of whole and fractional inches, pressure readings can be made. Normal atmospheric pressure will support a 29.92 in. column of mercury in such a device. Vacuum is expressed in "inches of mercury" (in. Hg.)

ABSOLUTE PRESSURE

Absolute pressure is any pressure above a perfect vacuum, and is expressed in terms of pounds per square inch *absolute,* or ***psia***. Absolute pressure measurements allow both vacuums and pressures above atmospheric to be expressed in the same units. A reading of 10 psia would be a partial vacuum (which could also be expressed as 20 in. Hg.); a reading of 20 psia would be well above the atmospheric pressure of 14.7 psia.

GAUGE PRESSURE

Gauge pressure is expressed in pounds per square inch *gauge* or ***psig.*** It is different from absolute pressure (psia) in that it totally ignores vacuum. Readings in psig measure only pressures *above* atmospheric–gauges are calibrated to read zero at atmospheric pressure. A reading in psig can easily be converted to the corresponding absolute value (psia) by adding atmospheric pressure (For example: 20 psig + 14.7 = 34.7 psi**a**). A simple way to remember the difference is that psig is pressure *above* atmospheric, and psia **includes** atmospheric pressure. The difference between the two is always 14.7 psi.

HIGH PRESSURE GAUGE

All refrigeration systems are divided into two sides, according to internal pressures. One side of the system operates at high pressure, the other at low pressure. A high pressure gauge, Fig. 9-11, is used to make readings on the high pressure side of the system. The scale on this gauge reads from zero (atmospheric pressure) to 500. Readings are in psig, because the zero point is calibrated

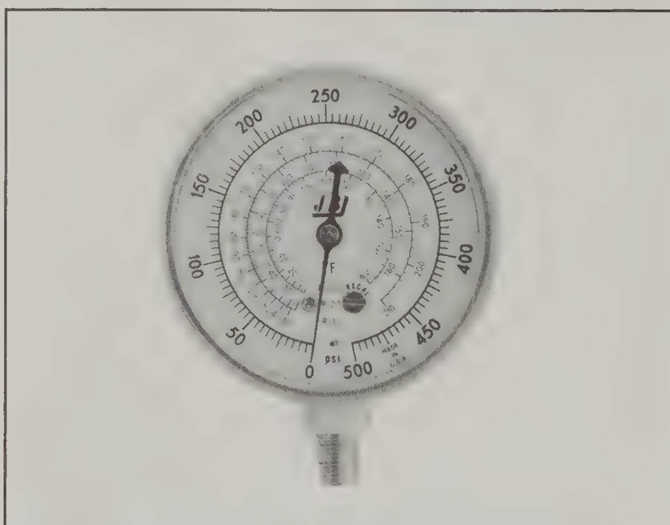


Fig. 9-11. A high-pressure gauge, used only for reading pressures above atmospheric. The zero point on this gauge actually represents a pressure of 14.7 psi (normal atmospheric pressure). To avoid confusion, pressure readings made with such a gauge are identified as "pounds per square inch gauge" (psig); *absolute* readings are 14.7 psi higher, and are identified as "psia." (J. B. Industries)

at atmospheric pressure. This gauge is usually color-coded red.

COMPOUND GAUGE

In refrigeration work, the service technician must frequently check and adjust the operating pressures of the system. As noted above, the system has high-pressure and low-pressure sides. The low-pressure side of the system normally operates at or above atmospheric pressure, but may slip into the vacuum area during certain operating conditions. A special gauge that displays two scales is used to read pressures both above and below atmospheric. Such gauges are called ***compound gauges*** and are usually color-coded blue. See Fig. 9-12.

Pressure readings

The compound gauge is calibrated with zero at atmospheric pressure and a scale that is accurate up to 120 psig. A special retarded area from 120 to 350 psig is provided to protect the gauge against overpressure but is *not* accurate. Pressure readings on the compound gauge are expressed as pounds per square inch gauge (psig).

Vacuum readings

The other scale on the compound gauge is used for vacuum readings. This scale is calibrated downward in inches of mercury (0 in. Hg. to 30 in. Hg.). This numbering system is the reverse of the one used on the mercury barometer used to measure atmospheric pressure changes. On the compound gauge, 30 in. Hg. indicates a perfect vacuum.

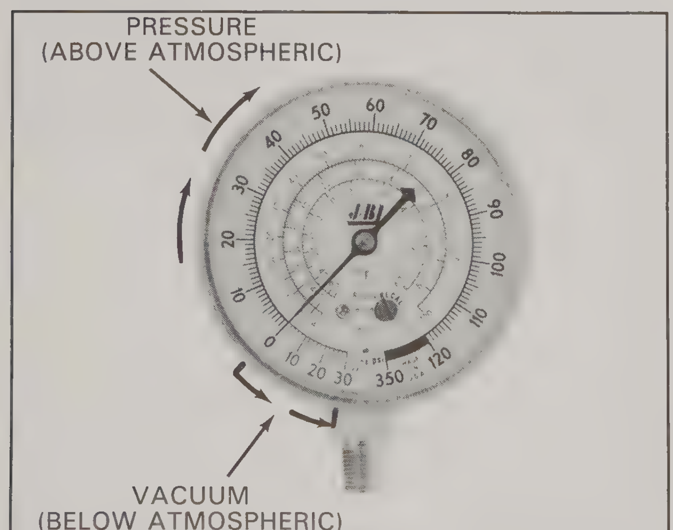


Fig. 9-12. A compound gauge makes possible both pressure and vacuum readings. The zero point is atmospheric pressure; pressure readings are above zero, and vacuum readings below. Vacuum values are the *opposite* of the scale used with the mercury barometer: normal atmospheric pressure is zero, and a perfect vacuum is 30. (J. B. Industries)

Rounding off readings

For practical purposes, most technicians "round off" atmospheric pressure from 14.7 psia to 15 psia, and perfect vacuum from 29.92 in. Hg. to 30 in. Hg. Therefore, atmospheric pressure becomes 15 psia (or 0 in. Hg.) and a perfect vacuum becomes 30 in. Hg. From this information, it can be seen that in rounded terms, every pound of atmospheric pressure equal to two inches of mercury. This is called a 2:1 ratio (2 in. Hg. = 1 psia).

When the compound gauge needle is in the vacuum scale, the reading is expressed in *inches* (in. Hg.). When the needle is in the pressure scale, the reading is expressed in *pounds* (psig). This difference is important.

GAS LAWS

Refrigerants are the vital working fluids in any system, because they are the vehicle used to transport heat from one location to another. All refrigeration systems are constantly changing a liquid to a gas, and the gas back to a liquid for another cycle. The technician **must** fully understand the behavior of gases to read pressure gauges and diagnose system problems accurately.

Gas laws deal with only three items: *temperature, pressure,* and *volume.* The gas laws prove the relationships of the items in such a manner that if one changes, they predict exactly how the others are affected. A gas law establishes the fact that the gas will *always* behave according to the rule, with no exceptions. These laws are so exact that the behavior of the temperature-pressure-volume relationship can be predicted and controlled.

BOYLE'S LAW

Robert Boyle (1627-1691) was an English scientist who was among the first to practice chemistry as a true science. He is best known today for the gas law that bears his name. ***Boyle's Law*** explains the relationship between pressure and volume of a gas, if the temperature remains constant (does not change). Boyle's Law states:

> *"The pressure of a gas varies inversely* (opposite) *as the volume, provided the temperature remains constant."*

Fig. 9-13 is an example of this law: If 2 cubic feet of gas at 50 psia is compressed to 1 cubic foot (volume reduced by half), the pressure will double to 100 psia, provided the temperature remains constant.

Of course, the opposite is true also: if the volume is doubled, the pressure is halved. Thus, you can say that when either the pressure or volume is changed, the corresponding pressure or volume is changed in the *opposite* direction (in exact proportion).

Each of the gas laws can be proven mathematically. The math is used to illustrate the behavior of gases and how they follow the law. When working with gas law

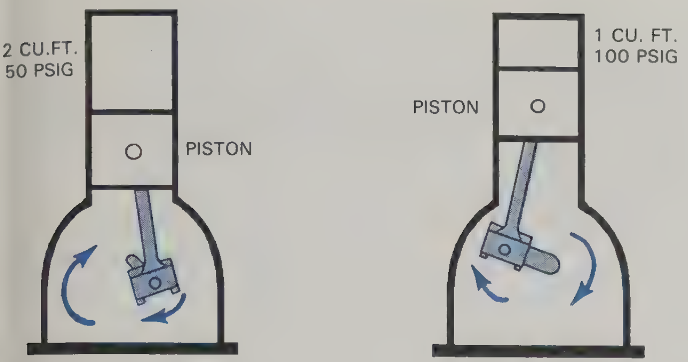


Fig. 9-13. Boyle's Law of Gases describes the inverse relationship of pressure and volume when temperature is constant: if volume is reduced by half, pressure will double. The reverse is true, as well: if volume is doubled, pressure will be halved.

formulas, remember that **absolute** pressures and temperatures must *always* be used.

The formula for Boyle's Law of gases is:

$$Po \times Vo = Pn \times Vn$$

(old pressure × old volume = new pressure × new volume).

Notice that temperature does not appear in Boyle's formula because the temperature remained constant. Only the pressure and volume changed. The old conditions are on the left of the equal sign and the new conditions are on the right. The equal sign actually says, "the same as." The principle of the formula means that when you multiply the old conditions, the answer will be the same as when you multiply the new conditions. For example, in the equation $10 \times 3 = 5 \times 6$, both sides equal 30.

In practice, the problem will always provide three numbers, or *values,* but the unknown fourth value must be discovered by using division.

$10 \times 3 = 5 \times ?$
$30 = 5 \times ?$
$30 \div 5 = 6$

Now try an actual Boyle's Law problem: What is the new volume if 6 cu.ft. of gas at 35 psig is compressed to 85 psig, providing the temperature stays constant? (Remember to use *absolute* pressures.)

$Po \times Vo = Pn \times Vn$
$50 \times 6 = 100 \times ?$
$300 = 100 \times ?$
$300 \div 100 = 3$ cu. ft. (Answer)

In this problem, the pressure doubled (50 psia to 100 psia), so therefore the volume should be reduced by half. Is it? Yes, from 6 cu.ft. to 3 cu.ft.

CHARLES'S LAW

As with every great invention or discovery, there is always someone who will make improvements or carry an experiment a step farther. In 1787, the French scientist Jacques Charles (1746-1823) performed some experiments that expanded upon the work done by Boyle a century earlier. He was aware that temperature would not always stay constant, and performed various experiments to determine how gases would behave when temperature became a ***variable*** (factor that changes).

In these experiments, he still maintained a constant (either pressure or volume). He was mainly concerned with what happened to the pressure or volume when the temperature was changed. He did indeed prove that gases behave consistently with temperature changes. Stated as ***Charles's Law:***

> *"At a constant pressure, the volume of a confined gas varies directly as the absolute temperature; at a constant volume, the absolute pressure varies directly as the absolute temperature."*

This is actually *two* laws expressed in one sentence. Charles's Law first deals with constant pressure, then with constant volume. We will consider the two laws separately.

Constant pressure

The formula for Charles's Law is:

$$Vo \times Tn = Vn \times To$$

(old volume × new temperature = new volume × old temperature)

Notice that *Tn* and *To* do not follow the form of Boyle's equation, with "old on the left and new on the right" of the equal sign. Pressure and volume do follow this formula, but temperature does not. Otherwise, the equation works just like Boyle's.

Always remember to use absolute temperatures whenever you apply Gas Laws. Fahrenheit is easily converted to Fahrenheit Absolute (Rankine) by *adding* 460 degrees to the Fahrenheit temperature. Absolute zero is 460 degrees lower than regular Fahrenheit zero. (Refer to Fig. 9-4). For example, $30°F + 460 = 490°F_A$ (490°R.)

Celsius is just as easily converted to Celsius Absolute (Kelvin) by *adding* 273 degrees to the Celsius temperature. Absolute zero is 273 degrees lower than regular Celsius zero. (Refer to Fig. 9-4). For example, $10°C + 273 = 283°C_A$ (283°K.)

Charles proved that, with a constant pressure, a temperature increase will result in a volume increase (in exact proportion). In other words, temperature and volume will change together. If one goes up, the other does also. If one goes down, the other goes down.

Example 1: You raise 5 cubic feet of gas at 40°F to 140°F at constant pressure. What is the new volume?

$Vo \times Tn = Vn \times To$ ($To = 40°F + 460 = 500°F_A$)
$5 \times 600 = ? \times 500$ ($Tn = 140°F + 460 = 600°F_A$)
$3000 = ? \times 500$
$3000 \div 500 = 6$ cu.ft. (Answer)

The temperature went up by 100 degrees, from 500° F_A to 600°F_A, while the volume went from 5 to 6 cubic feet. The volume and temperature increased in exact proportion, just as Charles's Law said it would.

Example 2: At a constant pressure, what is the new temperature of 2 cu.ft. of gas at 12°C when the volume is increased to 4 cu.ft.?

$$Vo \times Tn = Vn \times To$$
$$2 \times ? = 4 \times 285$$
$$2 \times ? = 1140$$
$$1140 \div 2 = 570°C_A \text{ (Answer)}$$

In this problem, the volume was doubled (2 cu.ft. to 4 cu.ft.), so the temperature should also double. Did it? Yes, from 285°C_A to 570°C_A. See Fig. 9-14.

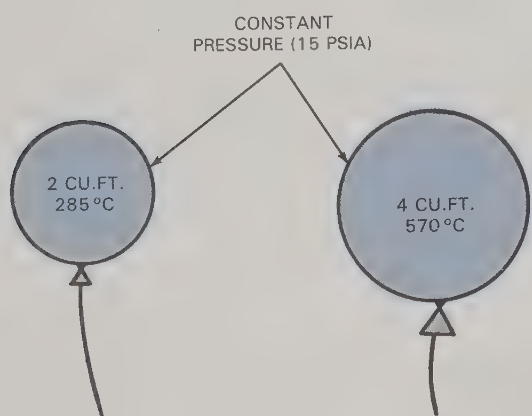


Fig. 9-14. According to Charles's Law of Gases, volume and temperature change in exact proportion to each other if pressure is constant. In this example, doubling the volume of the gas also doubles the temperature.

Constant volume

This part of Charles's Law is **very** important to all technicians, since refrigeration systems are completely sealed and, therefore, maintain a *constant volume.* The pressures and temperatures in these systems are easily controlled, because the volume remains constant. Charles's Law will prove that when the pressure goes up, the temperature will also go up; when the temperature goes down, the pressure will also go down, in exact proportion. This law illustrates a very important principle in refrigeration: if the pressure is controlled, the temperature will also be controlled, and vice-versa. When solving Charles's Law problems, remember to convert gauge and temperature readings to absolute pressure and temperature.

Example 1: What is the new pressure of a confined gas at 40°F and 35 psig, if the temperature is raised to 90°F?

$$Po \times Tn = Pn \times To$$
$$50 \times 550 = ? \times 500$$
$$27{,}500 = ? \times 500$$
$$27{,}500 \div 500 = 55 \text{ psia (Answer)}$$

Notes: Po = 35 psig + 15 = 50 psia
To = 40°F + 460 = 500°F_A
Tn = 90°F + 460 = 550°F_A

In this problem, the temperature was raised from 500°F_A to 550°F_A. Therefore, the pressure should also have increased in exact proportion. Did it? Yes, from 50 psia to 55 psia.

Example 2: What is the new temperature of a confined gas at 20 psig and 4°C, if the pressure is changed to 55 psig? (Can you predict the answer?)

$$Po \times Tn = Pn \times To$$
$$35 \times ? = 70 \times 277$$
$$35 \times ? = 19{,}390$$
$$19{,}390 \div 35 = 554°C_A \text{ (Answer)}$$

Notes: Po = 20 psig + 15 = 35 psia
Pn = 55 psig + 15 = 70 psia
To = 4°C + 273 = 277°C_A

In this problem, the pressure was doubled (from 35 psia to 70 psia), so the temperature should also double (277°C_A to 554°C_A). By converting these temperatures back to Celsius (4°C and 281°C), it can readily be seen that a large increase in pressure can have a drastic effect on temperature.

SATURATION TABLES

Thanks to the principles discovered years ago by Jacques Charles, saturation tables have been compiled to illustrate the temperature-pressure relationship for refrigerants. A chart like the one shown in Fig. 9-15 is a regular working tool of all refrigeration and air conditioning technicians and engineers. Pocket-size versions of these charts are usually available free from the local refrigeration parts supplier. Proper use of this chart is fully explained in Chapter 12, Refrigerants.

Whenever a pure gas is confined within a constant volume (refrigeration system), this chart will reveal the *saturation temperature and pressure* for each refrigerant. For example, if refrigerant R-12 is at a temperature of 10°F, the pressure will be 14.6 psig. These tables do not reveal superheat or subcooling, which are explained in a later chapter.

TRUE GAS EQUATION

In some areas of engineering, situations can develop in which there is no constant. All three factors (temperature, pressure, and volume) will change. There is a mathematical formula to handle this situation. Since it requires higher skills in mathematics, it is not used in everyday refrigeration work, but is valuable for scientific calculations and helpful in understanding engineering problems involving the performance of different gases. This formula combines Boyle's Law and Charles's Law.

$$\frac{P \times Vo}{To} - \frac{Pn \times Vn}{Tn}$$

SATURATION CHART

Italics Indicate inches Mercury — Pressure numbers indicate psig

TEMP.		REFRIGERANT NUMBER AND CYLINDER COLOR CODE									
F°	C°	Silver 717	Orange 11	White 12	Green 22	Purple 113	R123	R134a	Yellow 500	Orchid 502	Aqua 503
-50	-45.6	*14.3*	*28.9*	*15.4*	*6.2*		*29.2*	*18.6*	*12.8*	0.0	86.1
-45	-42.8	*11.7*	*28.7*	*13.3*	*3.0*		*29.0*	*16.6*	*10.0*	2.0	95.2
-40	-40.0	*8.7*	*28.4*	*11.0*	*0.5*		*28.8*	*14.7*	*7.6*	4.3	108.0
-35	-37.2	*5.4*	*28.1*	*8.4*	2.5		*28.6*	*12.3*	*4.8*	6.7	118.8
-30	-34.4	*1.6*	*27.8*	*5.5*	4.8	*29.3*	*28.3*	*9.7*	*1.2*	9.4	133.0
-25	-31.7	1.3	*27.4*	*2.3*	7.3	*29.2*	*28.1*	*6.8*	1.2	12.3	145.4
-20	-28.9	3.6	*27.0*	0.6	10.1	*29.1*	*27.7*	*3.6*	3.2	15.5	161.0
-18	-27.8	4.6	*26.8*	1.3	11.3	*29.0*	*27.6*	*2.2*	4.1	16.6	166.5
-16	-26.7	5.6	*26.6*	2.1	12.5	*29.0*	*27.4*	*0.7*	5.0	18.1	172.9
-14	-25.6	6.7	*26.4*	2.8	13.8	*28.9*	*27.3*	0.4	5.8	19.5	179.4
-12	-24.4	7.9	*26.2*	3.7	15.1	*28.8*	*27.1*	1.2	6.8	21.0	186.1
-10	-23.3	9.0	*26.0*	4.5	16.5	*28.7*	*26.9*	2.0	7.8	22.6	193.0
-08	-22.2	10.3	*25.8*	5.4	17.9	*28.6*	*26.7*	2.8	8.8	24.2	200.1
-06	-21.1	11.6	*25.5*	6.3	19.3	*28.5*	*26.5*	3.7	9.9	25.8	207.3
-04	-20.0	12.9	*25.3*	7.2	20.8	*28.4*	*26.3*	4.6	11.0	27.5	214.7
-02	-18.9	14.3	*25.0*	8.2	22.4	*28.3*	*26.1*	5.5	12.1	29.3	222.3
0	-17.8	15.7	*24.7*	9.2	24.0	*28.2*	*25.8*	6.5	13.3	31.1	230.0
2	-16.7	17.2	*24.4*	10.2	25.6	*28.1*	*25.6*	7.5	14.5	33.0	238.0
4	-15.6	18.8	*24.1*	11.2	27.3	*28.0*	*25.3*	8.6	15.7	34.9	246.2
6	-14.4	20.4	*23.8*	12.3	29.1	*27.9*	*25.1*	9.7	17.0	36.9	254.5
8	-13.3	22.1	*23.4*	13.5	30.9	*27.7*	*24.8*	10.8	18.4	38.9	263.0
10	-12.2	23.8	*23.0*	14.6	32.8	*27.6*	*24.5*	12.0	19.7	41.0	271.8
12	-11.1	25.6	*22.7*	15.8	34.7	*27.5*	*24.2*	13.2	21.1	43.2	280.7
14	-10.0	27.5	*22.3*	17.1	36.7	*27.3*	*23.9*	14.4	22.6	45.4	289.9
16	-8.9	29.4	*21.9*	18.4	38.7	*27.1*	*23.5*	15.7	24.1	47.7	299.2
18	-7.8	31.4	*21.5*	19.7	40.9	*27.0*	*23.2*	17.1	25/7	50.0	308.8
20	-6.7	33.5	*21.1*	21.0	43.0	*26.8*	*22.8*	18.4	27.3	52.5	318.5
22	-5.6	35.7	*20.6*	22.4	45.3	*26.6*	*22.4*	19.9	28.9	55.0	328.5
24	-4.4	37.9	*20.1*	23.9	47.6	*26.4*	*22.0*	21.4	30.6	57.5	338.7
26	-3.3	40.2	*19.7*	25.4	50.0	*26.2*	*21.6*	22.9	32.4	60.1	349.1
28	-2.2	42.6	*19.1*	26.9	52.4	*26.0*	*21.2*	24.5	34.2	62.8	359.7
30	-1.1	45.0	*18.6*	28.5	54.9	*25.8*	*20.7*	26.1	36.0	65.6	370.6
32	0.0	47.6	*18.1*	30.1	57.5	*25.6*	*20.2*	27.8	37.9	68.4	381.7
34	1.1	50.2	*17.5*	31.7	60.1	*25.3*	*19.7*	29.5	39.9	71.3	393.0
36	2.2	52.9	*16.9*	33.4	62.9	*25.1*	*19.2*	31.3	41.9	74.3	404.5
38	3.3	55.7	*16.3*	35.2	65.6	*24.8*	*18.7*	33.1	43.9	77.4	416.2
40	4.4	58.6	*15.6*	37.0	68.5	*24.5*	*18.1*	35.0	46.1	80.5	428.2
42	5.6	61.6	*15.0*	38.8	71.5	*24.2*	*17.5*	37.0	48.2	83.8	440.5
44	6.7	64.7	*14.1*	40.7	74.5	*23.9*	*16.9*	39.0	50.5	87.0	452.9
46	7.8	67.9	*13.6*	42.7	77.6	*23.6*	*16.3*	41.1	52.8	90.4	465.6
48	8.9	71.1	*12.8*	44.7	80.8	*23.3*	*15.6*	43.2	55.1	93.8	478.5
50	10.0	74.5	*12.0*	46.7	84.0	*22.9*	*15.0*	45.4	57.6	97.4	491.7
55	12.8	83.4	*10.0*	52.0	92.5	*22.1*	*13.1*	51.2	64.1	106.6	517.3
60	15.6	92.9	*7.8*	57.7	101.6	*21.0*	*11.2*	57.4	71.0	116.4	551.8
65	18.3	103.1	*5.4*	63.8	111.2	*19.9*	*9.0*	64.0	78.1	125.8	598.7
70	21.1	114.1	*2.8*	70.2	121.4	*18.7*	*6.6*	71.1	85.8	136.6	
75	23.9	125.8	0.0	77.0	132.2	*17.3*	*4.1*	78.6	93.9	147.9	
80	26.7	138.3	1.5	84.2	143.6	*15.9*	*1.3*	86.7	102.5	159.9	
85	29.4	151.7	3.2	91.8	155.6	*14.3*	0.9	95.2	111.5	172.5	
90	32.2	165.9	4.9	99.8	168.4	*12.5*	2.5	104.3	121.2	185.8	
95	35.0	181.1	6.8	108.3	181.8	*10.6*	4.2	113.9	131.3	199.7	
100	37.8	197.2	8.8	117.2	195.9	*8.6*	6.1	124.1	141.9	214.4	
105	30.6	214.2	11.1	126.6	210.7	*6.4*	8.1	143.9	153.1	229.7	
110	43.3	232.3	13.4	136.4	226.3	*4.0*	10.2	146.3	164.9	245.8	
115	46.1	251.5	15.9	146.8	242.7	*1.4*	12.6	158.4	177.4	266.1	
120	48.8	271.7	18.5	157.7	259.6	*0.7*	15.0	171.1	190.3	280.3	
125	51.7	293.1	21.3	169.1	277.9	2.2	17.7	184.5	204.0	298.7	
130	54.4		24.3	181.0	296.8	3.7	20.5	198.7	218.2	318.0	
135	57.2		27.4	193.5	316.5	5.4	23.5	214.5	233.2	338.1	
140	60.0		30.8	206.6	337.2	7.2	26.7	229.2	248.8	359.2	
145	62.8		34.4	220.3	358.8	9.2	30.2	245.6	263.7	381.1	
150	65.6		38.2	234.6	381.5	11.2	33.8	262.8	280.7	404.0	

Fig. 9-15. Saturation tables show temperature-pressure relationships for various refrigerants. These quick-reference charts are easy to use. For example, at 32 °F, the pressure for refrigerant R-22 is 57.5 psig. For refrigerant R-12 at the same temperature, the pressure is only 30.1 psig.

DALTON'S LAW OF PARTIAL PRESSURES

From 1803 to 1810, the English schoolteacher John Dalton (1766-1844) conducted a series of experiments that added greatly to our knowledge of gases and atoms. ***Dalton's Law*** deals with a *mixture* of gases rather than a single, pure gas. He found that in a mixture of gases, each gas behaves as if it occupies the space alone. Therefore, to obtain the total pressure of a confined mixture of gases, you must add the pressure for each gas in the mixture. For example, if three different gases were occupying the same space, it would be necessary to add the pressure for each gas to obtain the total pressure. See Fig. 9-16.

$$\textit{Total pressure} = P1 + P2 + P3$$

This system of partial pressures is the basis of operation for older absorption-type refrigeration systems. Such systems contain at least two gases, ammonia and hydrogen. Today, however, the vast majority of refrigeration systems are of the compression type, designed to use a single, pure gas. If another gas (such as atmospheric air) enters the system, then Charles's Law no longer applies; Dalton's Law becomes effective.

Major problems will develop when another gas is permitted to enter the compression-type system. The pressures will not correspond with the temperature-pressure chart. Atmospheric air contains *moisture*, a violent enemy of the compression refrigeration system. The moisture will quickly form an acid and destroy the motor windings.

Poor service procedures are the primary cause of air entering the system. Various methods can be used to rid the system of air and moisture, but severe cases require major repairs. These procedures are not difficult, but are time-consuming and expensive. The problem can usually be prevented by using proper service procedures.

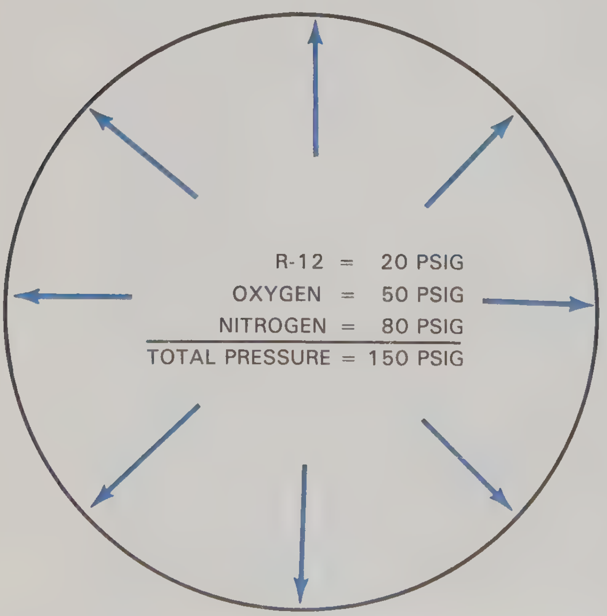


Fig. 9-16. Dalton's Law of Partial Pressures specifies that, in mixed-gas situations, the pressures of all the gases are added to obtain the total pressure.

SUMMARY

The fundamental principles explained in this chapter are the foundation for learning. Later chapters will build upon these principles and put them to practical use.

This chapter explained the different methods used to measure temperature and pressure. The ability to obtain accurate temperature and pressure readings is necessary for every technician. These readings reveal important information regarding system operation; later chapters will explore their significance.

Boyle's and Charles's Gas Laws were introduced and explained because temperature, pressure, and volume are important considerations for understanding the behavior of different refrigerants. The temperature-pressure relationship is very important when diagnosing system problems (troubleshooting) or adjusting controls. Application of these laws is fully explained in later chapters.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What is atmospheric pressure, stated in psig?
2. What is atmospheric pressure, stated in psia?
3. What is atmospheric pressure, stated in in. Hg., when using compound gauge.
4. Write "absolute zero" in the Fahrenheit, Celsius, Rankine, and Kelvin scales.
5. What is the new gauge pressure if 50 cubic feet of gas at 35 psig is compressed to 25 cubic feet?
6. What determines the temperature at which a substance will boil?
7. Temperatures between -250°F and absolute zero are known as __________ temperatures.
8. A compound gauge makes it possible to read both pressures __________ and __________ atmospheric, expressed in terms of in. Hg.
9. What is ambient temperature?
10. Boyle's Law of Gases says that pressure and volume will vary __________ , so long as the __________ stays constant.
11. Give the formula for Boyle's Law of Gases.
12. What is Charles's Law of Gases?
13. One of the formulas for Charles's Law is used for constant __________, the other for constant __________.
14. To what does Dalton's Law of Partial Pressures apply?
15. True or false? Any pressure less than atmospheric is called an absolute vacuum.

Chapter 10

BASIC REFRIGERATION CYCLE

After studying this chapter, you will be able to:
- *Draw a diagram of the basic refrigeration cycle.*
- *Describe the condition of the refrigerant in each component.*
- *Explain the purpose of each component of the refrigeration system.*
- *Identify refrigeration system component variations.*

NEW WORDS

accumulator	liquid line
basic refrigeration cycle	low-pressure side
compressor	makeup water
condensation	pressure drop
condenser	reciprocating
cut-in	refrigerant control
dissipated	series connection
evaporation	static
evaporator	suction line
forced convection evaporator	temperature difference
high-pressure side	vertical riser
hot gas discharge line	water-cooling tower

THE BASIC REFRIGERATION SYSTEM

All refrigeration and air conditioning systems are designed to contain and control a circulating refrigerant. This chapter describes and illustrates the ***basic refrigeration cycle,*** in which the circulating refrigerant absorbs unwanted heat at one location and carries it to a place where that heat can be discarded. Refrigerants are the vital working fluids in any system. They absorb heat by ***evaporation*** (changing from a liquid to a gas). They then release the heat through ***condensation*** (changing back to a liquid). In a properly operating system, the refrigerant will not break down, wear out, or become lost.

The compression system used in refrigeration is quite simple, if you understand the principles that were explained in Chapters 8 and 9. A thorough understanding of this basic system is important to your success as a technician, since all the "complicated" systems simply have one or more components added to make them more efficient, versatile, or serviceable.

The system equipment serves only to control the circulating refrigerant. Learning the basic system is not difficult. Committing it to memory will greatly assist in understanding later areas of study.

REFRIGERATION SYSTEM COMPONENTS

The basic system consists of seven components, Fig. 10-1. These components are so arranged that the refrigerant travels in a continuous cycle. It is necessary to understand the theory and operation of each system component, because malfunctioning of one component can greatly influence the operation of others. Being able to narrow the problem down to a particular component is important; so is understanding the condition of the refrigerant inside each component.

EVAPORATOR

The ***evaporator*** is a heat-exchanging device located within the area where heat is to be removed, Fig. 10-2. Liquid refrigerant inside the evaporator boils (evaporates) at a low temperature. During the evaporation

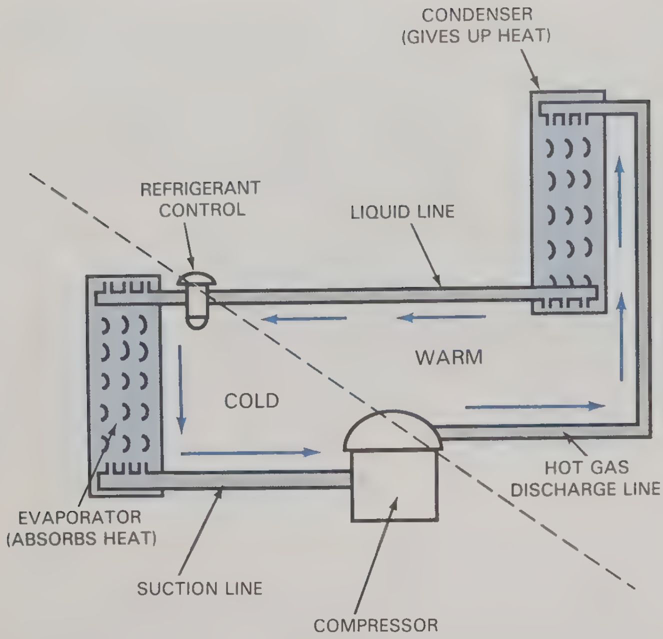


Fig. 10-1. The basic refrigeration system consists of seven components. The diagonal dashed line on this drawing represents the boundary between the low-pressure (cold) side of the refrigeration system and the high-pressure (warm) side.

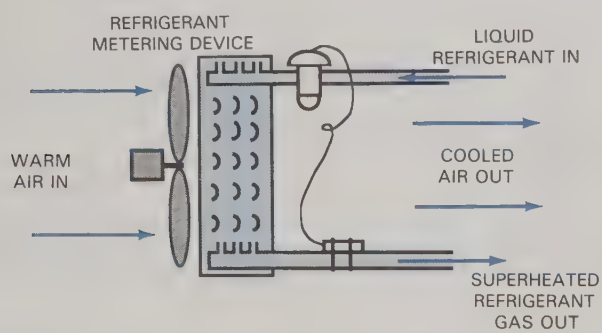


Fig. 10-2. As warm air passes through the fins of the evaporator, it gives up heat. The heat is conveyed by the fins to the copper tubing and, in turn to the liquid refrigerant. The added heat causes the refrigerant to boil (evaporate, or change state to a gas).

process, the refrigerant absorbs heat. A refrigerant that boils at a low temperature is selected, because a temperature difference must exist for heat to flow.

As shown in Fig. 10-3, the evaporator actually performs the purpose of the system, *refrigeration.* Heat always travels from hot to cold, so warm air passing through the fins of the evaporator will give up its heat to the colder evaporator. Heat travels through the fins to the copper tubing of the evaporator. The heat is then absorbed by liquid refrigerant traveling through the copper tubing. This causes the liquid to boil and vaporize. Saturated conditions (liquid at its boiling point) exist inside the evaporator tubing. The system must be designed to assure that all liquid boils off in the evaporator; only superheated gas (vapor) is permitted to leave the evaporator outlet. The normal amount of superheat

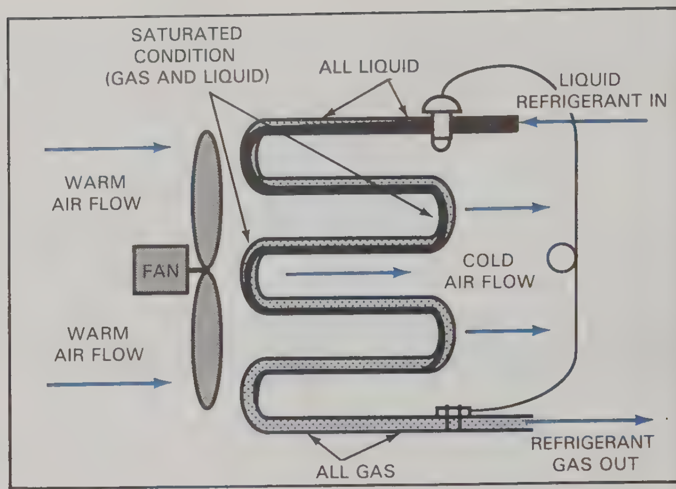


Fig. 10-3. As the liquid refrigerant inside the evaporator tubing absorbs heat from the air, it reaches a saturated condition and evaporates to a gaseous state.

at the evaporator outlet is 10°F (5.5°C). This provides maximum cooling effect and prevents liquid from leaving the evaporator.

Common refrigerants have boiling points ranging from -21°F to -50°F (-29°C to -46°C) at atmospheric pressure. Any liquid refrigerant boiling at this low temperature-pressure combination will indeed create the temperature difference needed to cause heat to travel from the air, through the evaporator, and into the liquid refrigerant.

Evaporator temperature difference

Refrigerant inside the evaporator tubing is in a low-temperature, low-pressure, saturated condition. The boiling point of the refrigerant is deliberately controlled to provide the necessary temperature difference to remove heat.

The precise function of the refrigeration system is to create a temperature within the evaporator that is about 20 degrees colder than air passing through the evaporator. See Fig. 10-4. The refrigerant is coldest (about 10 degrees colder than the evaporator). The evaporator, in turn, is about 10 degrees colder than the air flowing past its fins (the fins increase the surface area of the tubing and aid in the transfer of heat from air to tubing.)

The evaporator ***temperature difference*** (td) must exist in order to have heat transfer from hot to cold, as specified by the Second Law of Thermodynamics. This temperature difference only exists when the system is running (called the "on" cycle). As the temperature of the air over the evaporator becomes colder, the evaporator and the refrigerant also become colder, thus maintaining the 20 degree temperature difference.

When the entering air temperature reaches the desired lower temperature level, an air-sensitive thermostat will turn the system off. This stops the refrigeration process. The evaporator fan normally runs constantly, circulating air through the evaporator even when other

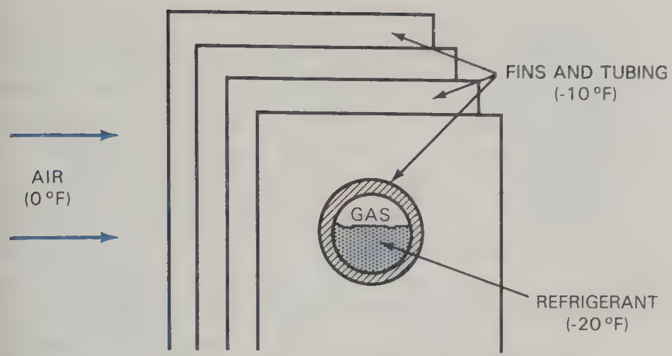


Fig. 10-4. A difference in temperature between the refrigerant and the outside air must exist for proper heat flow from hot to cold. Typically, the difference is about 20 degrees: the fins and evaporator tubing are 10 degrees colder than the air, and the refrigerant, in turn, is 10 degrees colder than the tubing and fins.

system components are off. This continuous air flow quickly warms the evaporator and refrigerant to the same temperature as the air. Therefore, no temperature difference exists during the "off" cycle. Refrigeration cannot be accomplished during the off cycle because no temperature difference exists.

The system is turned on when the rising air temperature reaches the ***cut-in*** (turn-on) point of the air-sensitive thermostat. Thus, the thermostat controls the temperature of the air inside the cabinet by controlling the on-and-off cycling of the system. See Chapter 23 for additional information on evaporator temperature differences.

SUCTION LINE

The ***suction line,*** usually made of copper tubing, connects the evaporator outlet to the compressor intake, Fig. 10-5. The suction line is normally insulated to prevent moisture-laden air from contacting the cold tubing and condensing. This eliminates any moisture or frost problems.

The refrigerant inside the suction line is a superheated gas, even at this low temperature. The compressor actually draws the gaseous refrigerant through this copper suction line much like a person sipping soda through a straw. The drawing or sucking action of the compressor creates the low pressure needed in the evaporator to provide a low boiling point for the liquid refrigerant.

Brazing is used to connect the suction line to the evaporator; the compressor connection may be brazed or flared. Regardless of the type of connection used, the suction line must be leakproof.

The condition of the refrigerant inside the suction line is a *low-temperature, low-pressure, superheated gas.* The superheat is obtained in the final pass of the evaporator and all the way through the suction line. Care must be exercised to prevent liquid refrigerant from entering the compressor, where it could cause severe damage.

COMPRESSOR

The ***compressor*** is a vital part of the system, but (even though its function is quite simple) probably the least understood. Compressors often are unjustly condemned as being "inefficient" when the problem is actually elsewhere. The technician must have a thorough understanding of exactly how the compressor performs its duties. Complete instructions on the actual operation of various types of compressors are found in Chapters 17 and 18.

The compressor is one of two division points that separate the ***low-pressure side*** of the system from the ***high-pressure side.*** See Fig. 10-6. The actual division point is located at the *valve plate* that contains the suction and discharge valve reeds.

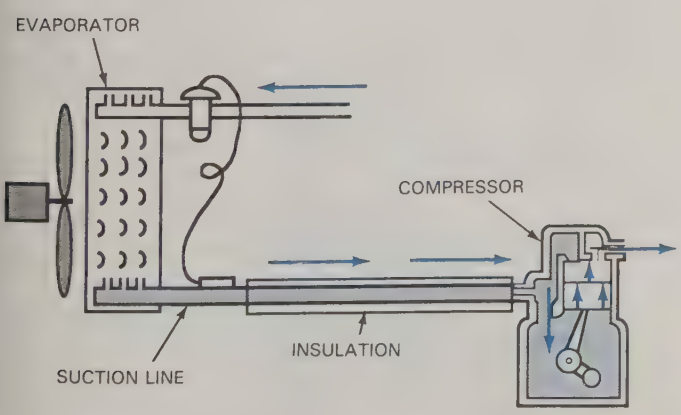


Fig. 10-5. The suction line connects the evaporator and the compressor, and is insulated to prevent condensation from forming on it and freezing. The line should contain only low-pressure, low-temperature gas–liquid refrigerant could damage the compressor.

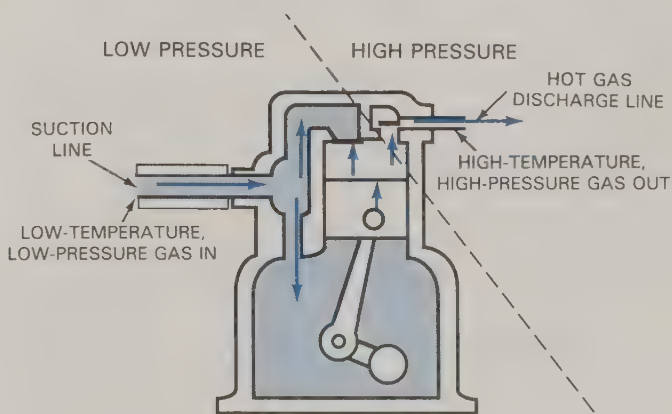


Fig. 10-6. The compressor is one of the division points between pressure regions in the refrigeration system. Low-temperature, low-pressure superheated gas enters the compressor and is squeezed (compressed) into a smaller volume. It exits the compressor as a high-temperature, high-pressure, highly superheated gas.

The purpose of the compressor is twofold. First, it must remove vapor from the evaporator (by the sucking action) to maintain a low boiling-point pressure inside the evaporator. Second, it must compress (squeeze) this low-temperature, low-pressure gas into a small volume, which will result in a high-temperature, high-pressure gas.

Reciprocating compressor

Reciprocating means moving first in one direction, then the opposite (back and forth, or up and down). This is the operating principle of the reciprocating compressor, Fig. 10-7, that is widely used in refrigeration systems. This compressor operates much like an automobile engine. It has two or more pistons, driven by a crankshaft that causes them to make alternating suction and compression strokes. At the top of each piston cylinder are two valve reeds: a suction valve reed and a discharge valve reed.

The downstroke of the piston creates a partial vacuum in the cylinder. This permits the low-pressure gas in the suction line to force open the suction valve reed and flow into the cylinder. On the up-stroke (compression stroke), increasing pressure in the cylinder allows the suction valve reed to close. The gas is compressed until the pressure within the cylinder overcomes the higher pressure in the hot gas discharge line that holds the discharge valve reed closed. This occurs at the top of the stroke, after the gas has been compressed to a much smaller volume and a much higher pressure and temperature. The discharge valve reed opens, allowing compressed refrigerant to flow into the hot gas discharge line.

The increased pressure created by the compressor pushes the refrigerant around the refrigeration system. Both the vacuum ("sucking action") on the low side of the compressor and the pushing action on the high side are important qualities in a compressor. A malfunction on either side will greatly affect the system: the compressor *must* perform both duties simultaneously to have a properly operating system. For this reason, most compressors have at least two pistons. While one piston is on the downstroke, the other is on the upstroke.

The operating pressures of the system are very important. The boiling point (temperature-pressure) inside the evaporator must be controlled to achieve the desired cooling effect. To maintain the correct boiling point, the compressor must be able to remove vapor from the evaporator at the same rate the liquid is boiling off (changing state to a gas). If the temperature-pressure inside the evaporator is permitted to rise, the boiling point will also increase (Charles's Law). This will reduce the cooling effect. Of course, the opposite is also true. Removing the vapor too fast (thus lowering its boiling point) will cause the evaporator to become too cold.

The compressor is the most expensive and critical component of the system. The compressor must be perfectly matched to other system components to balance the effect of refrigerant circulating within the system. The refrigerant must be pushed through the high side of the system at the same rate the vapor is being removed from the evaporator by the vacuum action of the compressor. If the refrigerant fails to circulate properly, problems will develop. All system problems can be traced to one of two causes:

- no refrigerant in the system
- poor circulation.

HOT GAS DISCHARGE LINE

The refrigerant being discharged by the compressor is in the form of a high-pressure, high-temperature gas. This hot gas from the compressor discharge travels through copper tubing to the condenser. See Figure 10-8. This copper tubing, Fig. 10-8, is called the ***hot gas discharge line.***

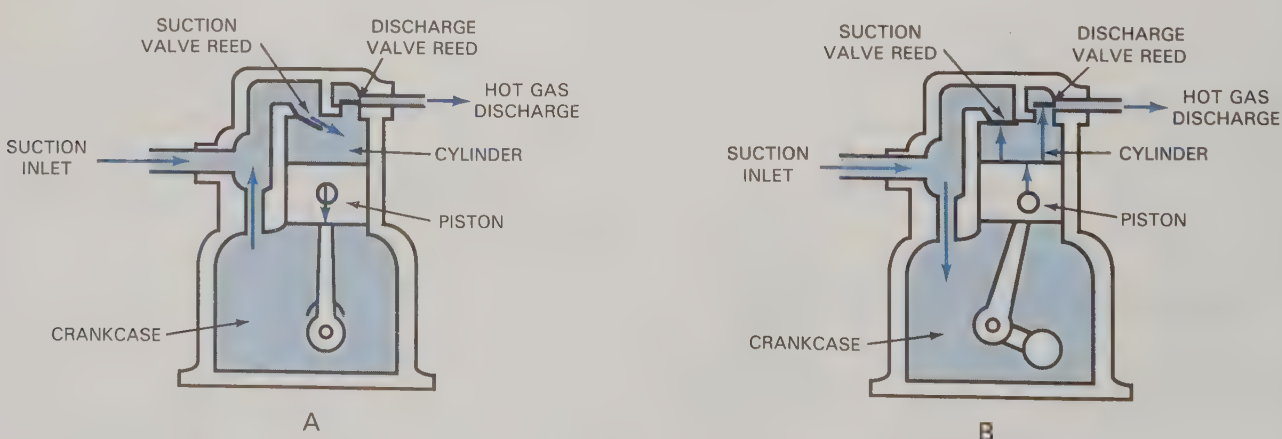


Fig. 10-7. Compressor operation. A–On the piston downstroke, lowered pressure in the cylinder allows low-pressure, low-temperature refrigerant gas to push open the suction valve reed and flow into the piston cylinder. High pressure in the discharge line holds the discharge valve reed closed. B–On the piston upstroke, increased pressure closes the suction reed valve. At the top of the piston stroke, pressure of the compressed gas is high enough to force open the discharge valve reed. High-pressure, high-temperature gas flows from the cylinder into the hot gas discharge line.

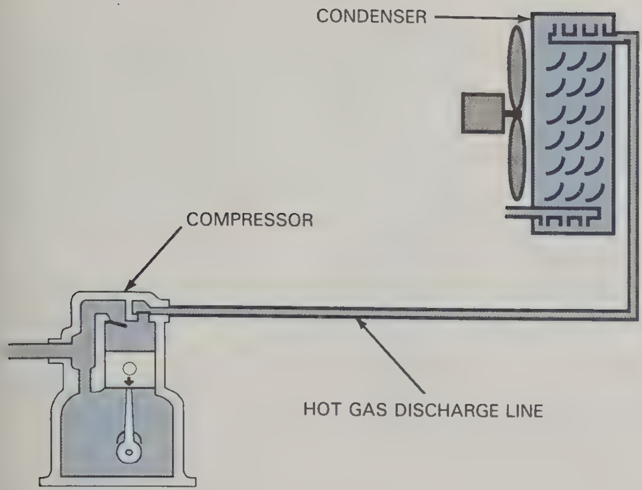


Fig. 10-8. The hot gas discharge line connects the compressor to the condenser. The gas it carries is both high-temperature and high pressure, so the connections must be leakproof.

This line is smaller than the suction line because the gas has been compressed to a smaller volume and higher pressure. While the suction line is cold or cool, the hot gas discharge line is hot. Due to the heat of compression, the discharge gas contains about 100 degrees of superheat (temperature above saturation). Since the line must carry the highly superheated gas at high pressure (from 100 psig to 350 psig or 690 kPa to 2413 kPa), it must be leakproof.

CONDENSER

The ***condenser*** is a heat exchanger, somewhat like the evaporator. While the evaporator is designed to absorb heat, the condenser is designed to give up heat. The sole purpose of the condenser is to remove heat from the superheated refrigerant vapor, causing the vapor to condense (change state) back to a liquid, Fig. 10-9. Only liquid should leave the condenser. Most condensers are cooled by the flow of ambient (surrounding) air through the fins, but some are water-cooled. The differences between air-cooled and water-cooled condensers will be explained later.

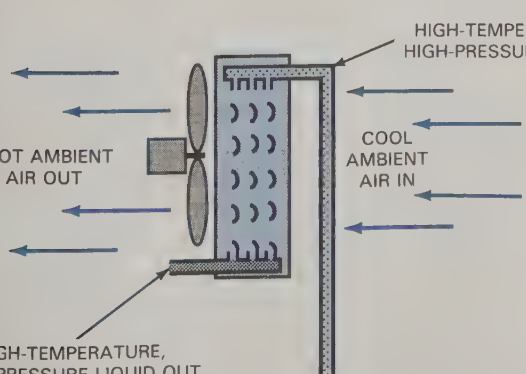


Fig. 10-9. The job of the condenser is to remove heat from the refrigerant gas and change its state back to liquid.

The higher pressure created by the compressor raises the saturation (boiling) point of the refrigerant to the point where ambient air can be used to:

- remove superheat to the saturation point (sensible heat).
- remove enough additional heat to cause the refrigerant to condense back to a liquid (latent heat).
- remove enough additional heat to partially subcool the liquid before it leaves the condenser (sensible heat).

In the first part of flow through the condenser, superheat is removed to lower the temperature of the high-pressure gas to the saturation point. Continued removal of heat causes a change of state from gas to liquid. This is possible because the higher pressure of the gas raised its saturation point above the temperature of the ambient air passing through the condenser. The main objective is to have all liquid refrigerant in the final lengths of the condenser tubing. This permits subcooling of the liquid before it leaves the condenser. The liquid is still under high-pressure, but the temperature is about lukewarm (saturation temperature).

For example, consider air at an ambient temperature of 70°F (21°C) passing through the condenser. On a system using R-12, compressing the gas will raise its saturation point to about 30 degrees *above* ambient air temperature, or 100 degrees (70 + 30 = 100) The saturation point for R-12 at 100°F (38°C) is 117 psig (807 kPa). Refer to Fig. 9-15.

The temperature of the highly superheated gas at the compressor discharge is about 200°F (93°C). Some superheat is ***dissipated*** (lost) as the gas travels through the uninsulated hot gas discharge line, so the gas arrives at the condenser at a temperature of about 150°F (66°C). Ambient air at 70°F (21°C) passing through the condenser will first remove all superheat (about 50 degrees), quickly lowering the temperature of the gas to the saturation point 100°F (38°C).

Ambient air continues to pass through the condenser, removing additional heat (latent heat), and causing the gas to condense back to a liquid. The final lengths of the condenser tubing should contain all liquid, and this liquid is easily subcooled by at least 10 degrees (sensible heat). Including this subcooling, the temperature of the liquid leaving the condenser will be about 90°F (32°C), lukewarm to the touch. Subcooling during the final condenser passages makes the system more efficient.

During the change of state (and subcooling) occurring in the condenser, the pressure will remain at 117 psig (807 kPa). Heat has been removed, but pressure readings will always indicate saturation pressure. Pressure gauges cannot read superheat or subcooling. Remember, at saturation (boiling point) you can have *all gas, a mixture, or all liquid,* depending upon how much heat has been removed.

LIQUID LINE

The copper-tubing ***liquid line*** connects the condenser outlet to the metering device called the "refrigerant control," Fig. 10-10. The liquid line should contain only *liquid* refrigerant that is subcooled by about 10 degrees. However, all liquid at the saturation point (with no subcooling) is also acceptable. This liquid refrigerant is still under high pressure (saturation pressure) and the tubing will be slightly warm to the touch. The refrigerant inside the liquid line is a high-temperature, high-pressure (preferably) subcooled liquid.

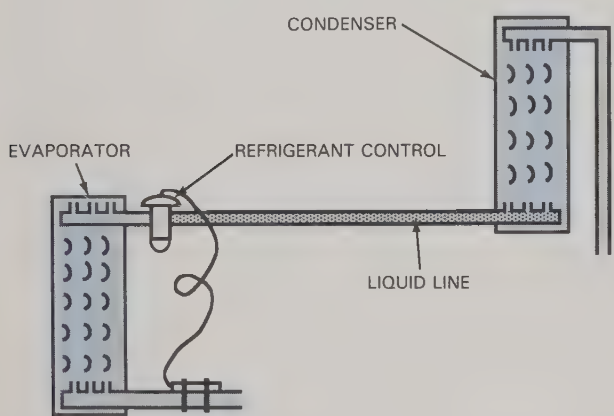


Fig. 10-10. The liquid line connects the condenser with the refrigerant control. Refrigerant leaving the condenser is a lukewarm liquid under high pressure.

REFRIGERANT CONTROL

The ***refrigerant control***, Fig. 10-11, is a device that plays a key role in the efficient and automatic operation of the system. This control must meter the flow of liquid refrigerant into the evaporator to assure that all liquid is boiled off before it enters the suction line. Allowing liquid refrigerant to reach the compressor will result in compressor failure.

The refrigerant control is the second division point between the high and low-pressure sides of the system

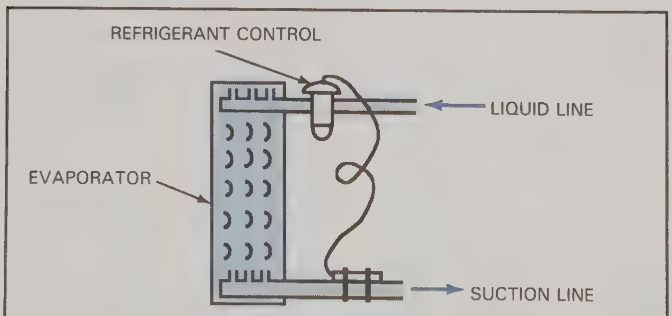


Fig. 10-11. The refrigerant control acts as a valve to meter the flow of liquid refrigerant into the evaporator. Metering is necessary to prevent liquid refrigerant from reaching and damaging the compressor

(the first, you will recall, is the compressor). The control is really a type of valve that works automatically to regulate the amount of liquid refrigerant entering the evaporator. At the control *inlet* is high-temperature, high-pressure, subcooled liquid. At the outlet of the control (as a result of a pressure drop across the valve), the liquid is in a low-temperature, low-pressure, saturated condition.

The amount of low-pressure liquid entering the evaporator is critical. The correct amount of liquid must be metered into the evaporator so that it boils off before it reaches the compressor. In other words, the amount of liquid entering the evaporator must be controlled to match the speed of evaporation. When the liquid boils rapidly, more liquid must pour into the evaporator. When the boiling process is slow, the valve must restrict the amount of liquid entering the evaporator.

There are different types of refrigerant controls; exactly how each one operates is explained in Chapter 14.

Condition of refrigerant in each component

The complete basic refrigeration system should be thoroughly understood and committed to memory before advancing to later areas of study. The system illustrated in Fig. 10-12 is the basis for all compression refrigeration systems, regardless of how large or small. To avoid confusion and misunderstanding, it is important to understand this basic system and the condition of the refrigerant within each of its components. Since refrigerant circulating within a system cannot be seen, thermometers and gauges are used to check system operation. The technician must know where to obtain these readings and diagnose problems correctly. Refer to Fig. 10-12 for location of the following components:

1. EVAPORATOR: low-temperature, low-pressure, saturated conditions.
2. SUCTION LINE: low-temperature, low-pressure, slightly superheated gas.
3. COMPRESSOR: division point between high and low-pressure.
   a. Inlet: low-temperature, low-pressure, slightly superheated gas.
   b. Outlet: high-temperature, high-pressure, highly superheated gas.
4. HOT GAS DISCHARGE LINE: high-temperature, high-pressure, highly superheated gas.
5. CONDENSER: high-temperature, high-pressure, saturated conditions.
6. LIQUID LINE: high-temperature, high-pressure, (preferably) subcooled liquid.
7. REFRIGERANT CONTROL: division point between high-pressure and low-pressure sections of system (the first cold spot in the system).
   a. Inlet: high-temperature, high-pressure, subcooled liquid.
   b. Outlet: low-temperature, low-pressure, saturated liquid.

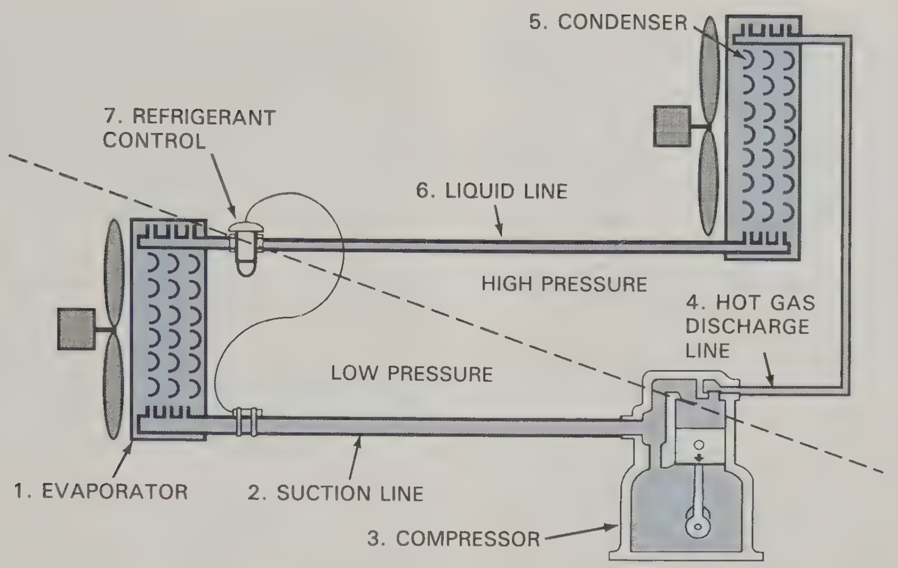


Fig. 10-12. The technician should know the condition of the refrigerant in each of the seven components of the basic refrigeration system. Although systems may vary in detail, the components shown are basic to all compression refrigeration systems. The diagonal line divides the system into the low-pressure (cold) side and the high-pressure (warm) side.

VARIATIONS IN BASIC REFRIGERATION COMPONENTS

Refrigeration components often will serve an identical purpose, but vary in size, style, shape, and location. These differences are necessary to save cost or space, or to improve efficiency. Variations in a number of major components are described in the following sections.

EVAPORATORS

Evaporators are made in many different shapes and sizes to fill specific design or operational needs. They can operate upon either the conduction or convection principle, and are classified under five different types:

1. Shell-type, used in domestic refrigerators.
2. Shelf-type, used in domestic upright freezers.
3. Wall-type, used in domestic chest freezers.
4. Plate-type, sometimes used in commercial systems and occasionally in domestic systems.
5. Finned-tube type, with forced convection. The most common, used in many applications.

Shell-type evaporator

The *shell-type evaporator,* Fig. 10-13, is commonly used as the freezing compartment in domestic refrigerators that do not have automatic defrost. This evaporator actually forms a metal box that becomes the freezer compartment. Food is placed inside the shell (or box) for freezing.

The shell-type evaporator is made of thin aluminum sheet; the refrigerant travels through passages built into the shell during the manufacturing process. Since aluminum is a good conductor of heat, the shell-type evaporator functions upon the principle of conduction and natural convection.

The main problem with this evaporator is the thin aluminum used in its construction. The metal is easily punctured, resulting in loss of refrigerant. Repairs are difficult, time-consuming, and expensive. Frost will accumulate on the evaporator and act as an insulator, preventing heat from getting to the evaporator. Proper

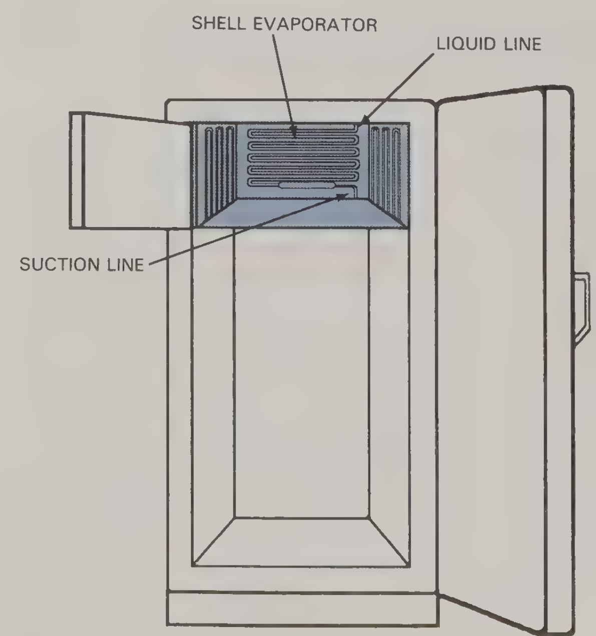


Fig. 10-13. The shell-type evaporator is commonly used for the freezing compartment of manual-defrost domestic refrigerators. The aluminum shell is easily damaged, so care must be exercised when defrosting.

defrosting is important, but the use of any sharp instrument is forbidden. Defrost is accomplished by turning the refrigerator off and placing a pan of hot water inside the evaporator. After the frost and water are removed, recovery to normal operating temperature is fairly rapid.

This evaporator includes an ***accumulator***, a small reservoir used as a safety device to trap any liquid refrigerant that did not evaporate during the passes around the evaporator. Liquid flowing into the accumulator will be evaporated before being drawn into the suction line.

Shelf-type evaporator

The *shelf-type evaporator,* Fig. 10-14, is used extensively in upright domestic freezers. The evaporator is made of aluminum tubing, which forms the shelves inside the freezer. Additional wires are soldered to the aluminum tubing to increase the strength and evaporator surface area of each shelf. Food containers are placed upon these shelves, with heat transfer accomplished by conduction and natural convection.

Because warmer air rises, one "shelf" of tubing, called the ceiling coil, is located in the uppermost part of the cabinet. Most upright freezers will have three or four shelves, not counting the ceiling coil. The refrigerant goes to the ceiling coil first, and then down through each of the shelves to the bottom. This is called a ***series connection*** because the refrigerant must travel through one shelf before going to the next.

This type of freezer is popular, because it is easy to select frozen foods from its organized shelving. The bad feature of this type is that every time the door is opened, cold air spills out the bottom and warm, moisture-laden air enters at the top. Frost readily accumulates on the ceiling coil and upper shelf. This excess frost will act as an insulator and prevent heat from getting to the evaporator. Proper manual defrosting must be done about once a year. Defrost is accomplished by turning the freezer off, removing any packages of frozen food, placing one or two pans of hot water inside the freezer and closing the door. Heat from the hot water will cause the temperature inside the freezer to rise rapidly, thus melting or loosening the accumulated frost which can then be removed by hand. Like the shell-type evaporator, the use of any sharp instrument when defrosting on a shelf-type is forbidden. The sharp instrument might puncture the aluminum evaporator, which would permit the refrigerant to escape. A puncture hole in the aluminum tubing is expensive to repair.

Wall-type evaporator

The *wall-type evaporator* is commonly used in chest-type domestic freezers. The evaporator tubing is made of steel or aluminum and is firmly attached to the outside surface of the inner cabinet liner.

This arrangement provides a smooth inside surface with uniform cooling throughout the cabinet. The rings of tubing go around the sides only, not across the bottom or the lid. The refrigerant travels through the top ring first and so on to the lowest ring. Heat transfer is by conduction and natural convection.

An advantage of the chest freezer over the upright is that cold air does not spill out when the door is opened. This principle reduces the amount of frost accumulation, requiring less-frequent defrosting (once every two or three years), and less running time (making it more energy efficient).

Plate-type evaporator

The commercial *plate-type evaporator,* Fig. 10-15, is usually made of steel, with the refrigerant traveling

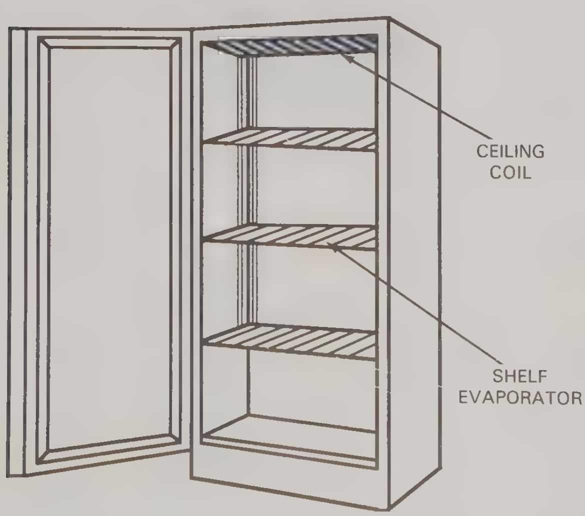


Fig. 10-14. The shelf-type evaporator is found in upright domestic freezers. The refrigerant tubing actually is used to form the shelves. A ceiling coil is used to cool air that rises to the top of the freezer

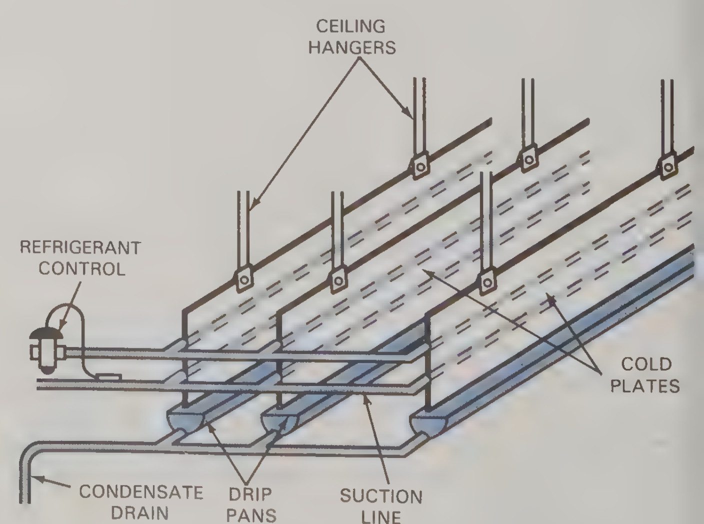


Fig. 10-15. The plate-type evaporator is used in older commercial-type installations, such as walk-in coolers. It usually hangs from the ceiling of the cooler, creating slow, steady air movement by natural convection.

through passages that were formed in the process of making the plate. These cold plates are usually hung from the ceiling, with drip pans made from sheet metal located below them to catch and drain off the condensate.

These plates operate on the principle of natural convection (hot air rises and cold air falls). As warm air rises and encounters the cold plates, it will give up its heat to the plates and then sink toward the floor. This method creates a constant, slow air movement that keeps temperature levels quite uniform.

This cold plate system is not common, but variations of it are often used in both domestic and commercial applications. The cold plate was the forerunner to the forced convection evaporator.

One type of cold plate is used in some domestic refrigerator-freezer combinations. This cold plate, made from aluminum, is located in the upper back section of the refrigerator compartment (not the freezer compartment). See Fig. 10-16. This cold plate is connected "in series" with the freezer evaporator. It cannot receive any liquid refrigerant until the freezer is satisfied and the leftover liquid reaches the refrigerator cold plate. In this system, the cold plate is actually a type of suction accumulator that prevents liquid floodback.

Finned-tube-type with forced convection

This type of evaporator is widely used in domestic, commercial, and industrial applications. The introduction of the finned-tube, forced-convection evaporator made possible remarkable advances in the field of refrigeration and air conditioning. The *forced convection evaporator* has an electric fan mounted so as to increase the airflow through the evaporator. Because of the large amount of air passing through the evaporator, its capacity in Btus per hour was increased dramatically.

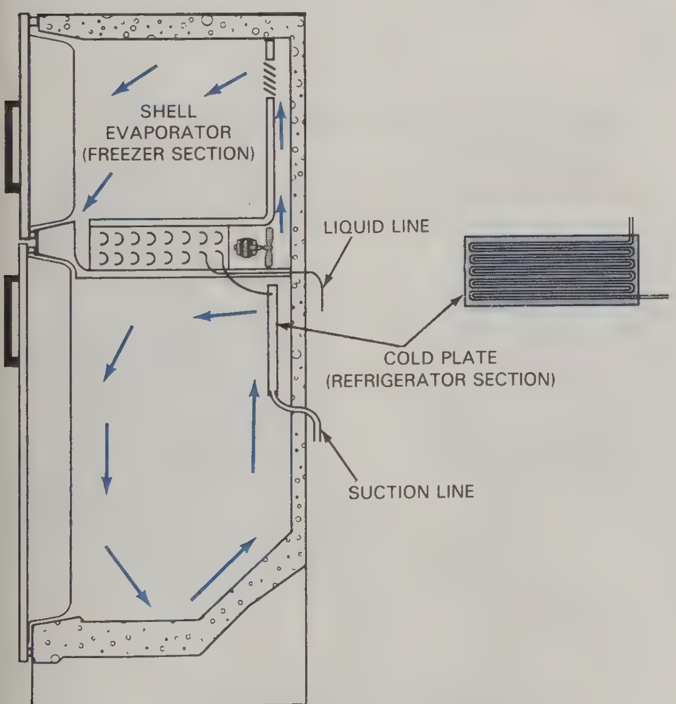


Fig. 10-16. A variation of the cold plate principle is used in some domestic refrigerator-freezer units. The plate is located at the back of the refrigerator section, and connected in series with the freezer compartment shell evaporator.

The forced convection system made it possible to accomplish large amounts of refrigeration (Btu/hr.) with a smaller evaporator and to do so more quickly.

The surface area of the evaporator tubing is greatly increased by the addition of fins. These are usually made of aluminum and are securely bonded to the tubing. Spacing of the fins is used to vary the capacity of the evaporator and compensate for depth. The fins must be kept straight and equally spaced or airflow will be reduced, which will (in turn) reduce the capacity of the evaporator. Most evaporators are designed for a specific airflow in cubic feet per minute (cfm); the design airflow should not be changed. Changing the capacity of the evaporator will affect operation of other system components, since they are sized and selected according to the original capacity.

SUCTION LINE

The correct size and proper installation of the suction line is important to the efficient operation of a refrigeration system. The size of the suction line (as well as the liquid line) is determined by several factors involving the condition of the gas inside it. These factors include velocity, pressure, volume, density, and pressure drop. The size of the copper tubing will vary according to the size of the system, ranging from 1/4 in. to 6 in. (6 mm to 152 mm) OD.

The gas-carrying capacity of the suction line is closely calculated to match the flow of gas from the evaporator to the compressor. A very long suction line, or one that has many bends or fittings will involve a *pressure drop.* An excessive (2 psi or greater) pressure drop in the suction line is equivalent to operating the compressor at a lower pressure, which reduces compressor capacity.

Due to the compressor's lubrication design, some oil will tend to circulate through the system along with the refrigerant. It is important that this oil return to the compressor and not become trapped somewhere in the system. Oil return will be improved by slanting the suction line downward from the evaporator to the compressor, so oil can drain naturally into the compressor. All horizontal suction lines should slope toward the compressor at the rate of 1/4 in. for each 10 ft. of tubing. If there is a low spot in the suction line, it will function as an oil trap, Fig. 10-17. Oil accumulates in such a trap and decreases the efficiency of flow. As the low spot becomes filled with oil, the vapor will build up a pressure against the slug of oil and the compressor will lower the pressure on the other side. As soon as the pressure difference overcomes the weight of the oil, the oil is sent back to the compressor.

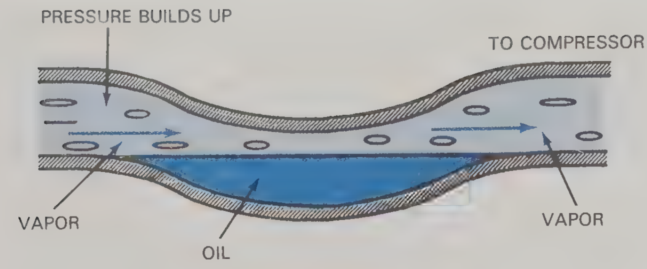


Fig. 10-17. A low spot in the suction line functions as an oil trap. As the oil accumulates, vapor pressure builds up on the evaporator side of the trap. Eventually, it will push the slug of oil to the compressor.

This trapping of oil is an advantage in commercial systems, where the condensing unit is located above the evaporator section. An oil trap is deliberately installed in the suction line at the base of the ***vertical riser,*** Fig. 10-18. The vertical riser is usually of smaller size tubing, which will increase the velocity of the refrigerant to help sweep the oil up the riser and back to the compressor.

Suction line insulation

Suction lines are usually insulated, for two reasons:

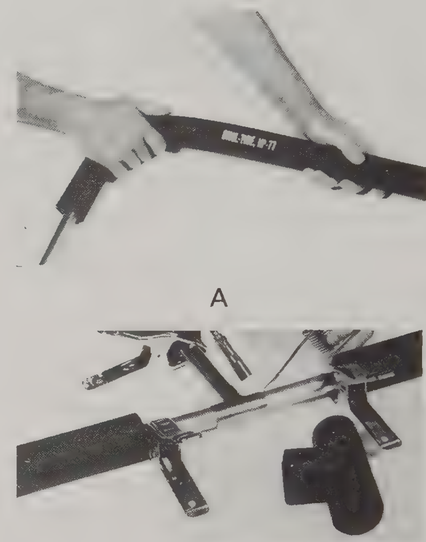
- To limit superheating of gas that would reduce compressor efficiency.
- To eliminate condensation that could cause frost and ice problems.

The superheated gas inside the suction line is in a low-temperature, low-pressure state. This cold gas is used to cool the compressor, so the amount of superheat gained through the copper tubing suction line must be limited. High superheat at the compressor inlet reduces compressor efficiency and causes damage due to excessive discharge superheat.

Insulating the suction line eliminates contact between moisture-laden atmospheric air and the cold copper tubing, preventing condensation. If moisture is allowed to condense on the copper tubing, it would drip and cause problems. If the suction line temperature is below 32°F (0°C), atmospheric moisture will freeze on the tubing, creating frost and ice problems.

Suction lines are usually insulated with a black, vaporproof flexible tubing. The tubing is available in four-foot lengths, with wall thicknesses of 3/8 in., 1/2 in., 3/4 in., or 1 in. The insulation is available with an inside diameter (ID) ranging from 3/8 in. to 4 in. or larger.

The insulation is installed by slipping it over copper tubing and elbows on new installations, Fig. 10-19. For existing systems, insulation is cut with a sharp knife to slip over tubing and fittings, Fig. 10-20. A special adhesive is applied to seal all cuts, seams, and butt joints.


A

B

Fig. 10-19. Installing insulation. A–Insulation is slipped onto tubing and over elbows in new installations. B–For tees and other fittings, the material can be cut and joined with adhesive. (Halstead)

RECIPROCATING COMPRESSOR STYLES

The compressor, Fig. 10-21, is the "heart" of the refrigeration system and is driven by an electric motor. The electric motor can be mounted outside the compressor or inside the same housing as the compressor.

Compressors are built in three basic styles:

- **Open-type.** This compressor is belt-driven from an external electric motor.

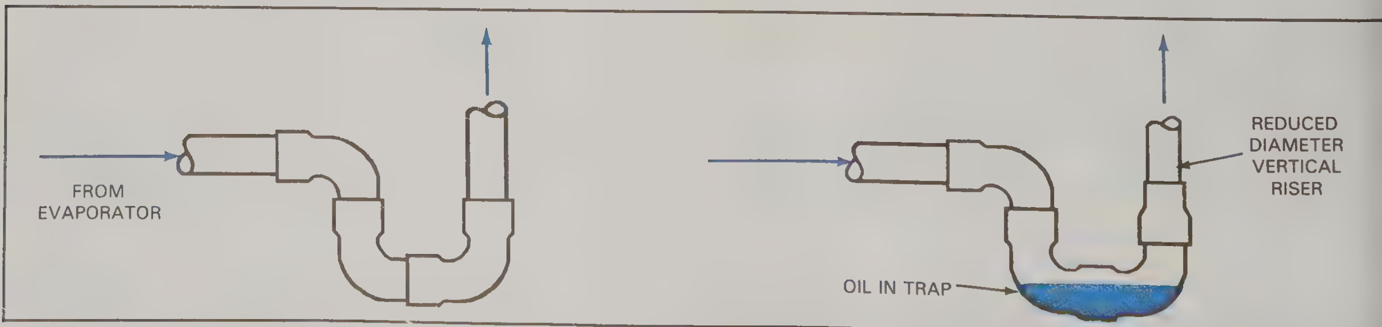
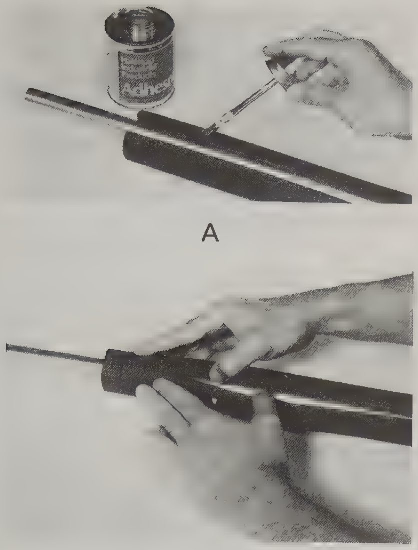


Fig. 10-18. An oil trap in a commercial installation. The vertical riser uses smaller-diameter tubing to increase refrigerant velocity and help sweep oil back to the compressor.



A

B

Fig. 10-20. Insulating existing installations. A–Insulation is slit to fit over tubing and fittings, then adhesive is applied. B–Adhesive bonds seams quickly when they are pressed together. (Halstead)

- **Semi-hermetic.** The electric motor and compressor are enclosed in a forged iron body that is sealed and bolted together. The motor shaft is directly connected to the compressor crankshaft.
- **Hermetic.** The motor and compressor are sealed within a steel body that is welded together. Like the semi-hermetic type, the compressor is directly driven from the motor shaft.

Both the open-type and semi-hermetic compressors are repairable. Since hermetic compressors are sealed within a welded enclosure, they cannot be repaired. Compressors and motors are fully explained in later chapters.

CONDENSERS

Like evaporators, condensers are available in a variety of shapes, sizes, and styles. Regardless of shape, size, or style, all condensers serve the same purpose: removing heat from the refrigerant. Depending upon the application, air-cooled condensers may operate upon natural or forced convection. Natural (***static*** convection condensers require a large surface area for proper heat removal. These condensers are often used in small domestic systems. Forced convection permits the use of smaller condensers, because the increased air flow removes heat faster.

The heat to be removed by the condenser comes from two sources:

- The heat absorbed by the refrigerant in the evaporator.
- The heat of compression added to the refrigerant in the compressor.

Compressing the refrigerant vapor will increase its temperature greatly because the heat is confined in a much smaller volume (Boyle's Law of Gases). By raising the temperature-pressure relationship, the condensing

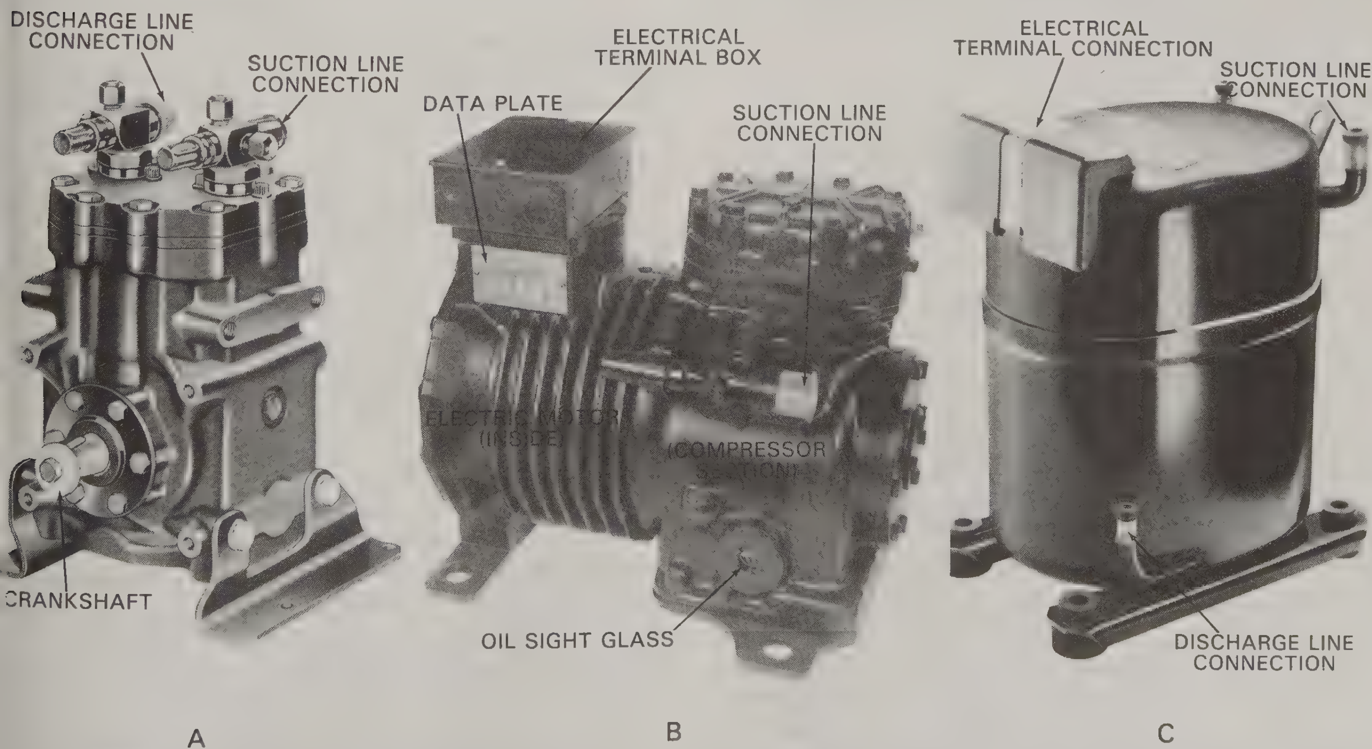


Fig. 10-21. Basic styles of reciprocating compressors. A–Open-type compressor, belt-driven by an external electric motor. (Tecumseh) B–Semi-hermetic-type compressor, with motor and compressor inside bolted-together housing. (Copeland) C–Hermetic-type compressor, with motor sealed inside welded metal shell. (Copeland)

(or boiling) point is also raised. This makes it possible to use ambient air (or water) as a cooling medium to condense the refrigerant back to a liquid.

In actual practice, the compressor must raise the temperature-pressure relationship about 30 degrees higher than ambient temperature. If the ambient cooling temperature goes up, the discharge pressure will also go up. Likewise, if the temperature of the cooling medium goes down, the discharge pressure also goes down. To illustrate:

On a system using R-12, with the temperature of the air entering the condenser at 70°F (21°C), the condensing temperature must be raised to about 100°F (38°C). By referring to the pressure-temperature tables, the corresponding condensing pressure would be about 117 psig (807 kPa).

However, if it were a hot summer day and the ambient temperature reached 95°F (35°C), the condensing temperature would be about 125°F (52°C). Therefore, the normal discharge pressure would be about 169 psig (1165 kPa).

This method of determining proper head pressure applies to all air-cooled condensers that use halogenated refrigerants, such as R-12, R-22, and R-502. The operating characteristics of R-502 deserve special consideration when determining normal condensing temperatures. R-502 is best considered with a temperature difference of 20 degrees (as compared to 30 degrees for R-12.) For example, with an ambient temperature of 80°F (27°C), the condensing temperature would be 100°F (38°C). Checking the pressure-temperature table would reveal a condensing head pressure of about 216 psig (1489 kPa).

Condenser cooling stages

As noted earlier, the refrigerant is cooled in three distinct stages as it circulates through the condenser:

1. The superheat of the gas is removed, cooling the gas down to the saturation point. (Sensible heat is removed)
2. The gas is condensed to a liquid. (Latent heat removed)
3. The liquid is subcooled to a point below its saturation point. (Sensible heat removed)

As soon as the superheat of the gas is removed, the saturation point has been achieved. Further heat removal will result in the gas condensing back to a liquid (hence the name *condenser*.) The main object is to remove enough heat so that all the gas will be condensed, leaving only liquid in the final part of the condenser, where subcooling can occur.

Air-cooled condensers are easy to install, inexpensive to maintain, and if sized properly, can be used satisfactorily in all regions. Water-cooled condensers are very efficient, but are expensive to operate and to keep clean. Water-cooled condensers are still used occasionally where cool ambient air is not available.

DOMESTIC CONDENSERS

Domestic refrigeration commonly use three types of air-cooled condensers:

- Finned-tube, forced convection.
- Wire static (natural convection).
- Wall static (natural convection).

Finned-tube, forced convection condenser

This is the most commonly used condenser. It is made of steel tubing with external aluminum fins that provide a larger and more efficient heat transfer surface. Heat transfer is efficiently accomplished by forcing large quantities of air through the compact tubing and fin assembly. See Fig. 10-9 for operation of a typical condenser of this type.

The forced convection condenser is generally preferred for commercial applications. With this condenser, it is important that an adequate supply of fresh air is available at all times. In order to achieve their compact size, these condensers are normally constructed with a small face (or surface area) and a depth of several rows of tubing. As the air is forced through the condenser, it absorbs heat from the refrigerant inside the tubes.

Most forced convection condensers use a fan that draws, rather than blows, air through the condenser. The draw-type fans result in more uniform airflow through the condenser, which is preferred because the even air distribution will increase condenser efficiency.

It is important that all air-cooled condensers be kept clean. The condenser fan will draw foreign material such as lint, dust, dirt, or leaves into the condenser. This foreign material acts as an insulator and prevents proper airflow.

A dirty condenser will cause the compressor to work harder. The condensing temperature-pressure must be raised to compensate for the reduced condenser capacity. This results in excessive discharge pressures, which will seriously affect the operation of the system. Cleaning the condenser is an easy, but often neglected task. Cleaning is accomplished by using a brush, vacuum cleaner, or other appropriate methods.

Wire static condenser

The wire static (natural convection) condenser, Fig. 10-22, is used on domestic refrigerators. This condenser consists of rows of steel tubing with lengths of wire attached to them. The wire increases the surface area of the steel tubing, permitting better heat transfer.

This condenser is mounted on the back of the refrigerator, making it important that the appliance not be placed tightly against a wall. A space of at least 4-6 in. (10-15 cm) must separate the back of the refrigerator from the wall to allow for natural convection air flow over the condenser.

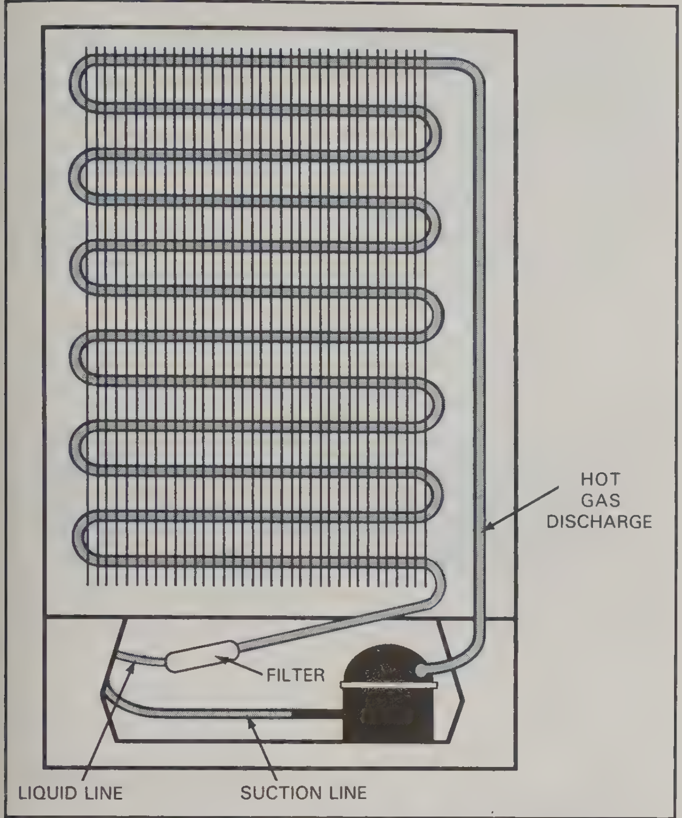


Fig. 10-22. The wire static condenser is generally used for domestic refrigerators. Care must be taken to allow sufficient air circulation space around the condenser for efficient cooling.

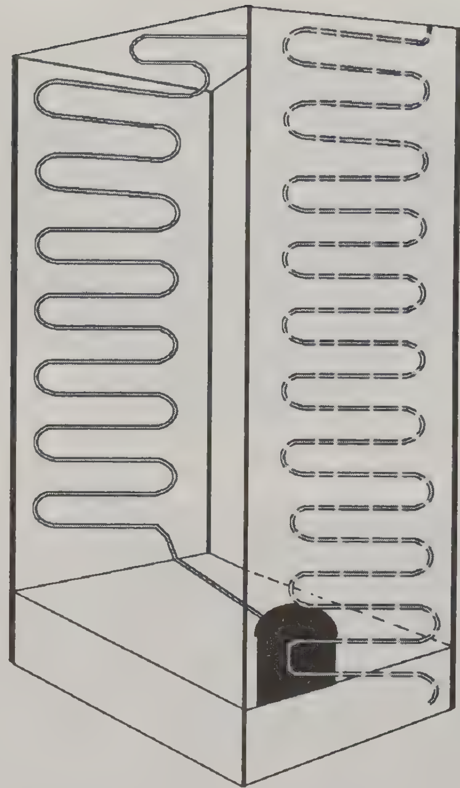


Fig. 10-23. The wall static condenser is mounted on the inner surface of the outer wall of a chest or upright freezer. A layer of insulation separates it from the evaporator, which is mounted on the inner wall. It is an efficient condenser design.

Wall static condenser

The wall static condenser is efficient, hidden from view, and space-saving. This type of condenser is used on both chest and upright domestic freezers. The condenser tubing is securely fastened to the inside surface of the outer shell, Fig. 10-23. A layer of insulation separates it from the inner shell (upon which the evaporator is mounted). This unit is actually a box inside a box, with insulation between the two boxes. Of course the inner box is very cold, while the outside of the freezer is warm to the touch. The insulation between the two boxes retards any heat flow between the two temperature levels. When installing these freezers in the home, allowance must be provided for proper airflow around the outside of the cabinet.

COMMERCIAL CONDENSERS

Forced convection, air-cooled condensers are most common in commercial systems, although water-cooled systems are not unusual. Air-cooled units are cheaper to operate and have fewer service problems. Commercial air-cooled condensers will vary greatly in size and style. Some outdoor units are mounted vertically; others are mounted horizontally, with one or more electric fans to draw air through the condenser. See Fig. 10-24.

Commercial water-cooled condensers

At one time, water-cooled condensers were very common. However, they have become costly to operate because the water is usually discharged into a sewer drain after passing through the condenser. Water and sewage service rates have increased due to the increased demand on facilities. In some cases, a water-cooling tower is installed on the roof to cool the water for recirculation through the condenser. As a result of increasing costs, many water-cooled systems are being converted to air-cooled systems.

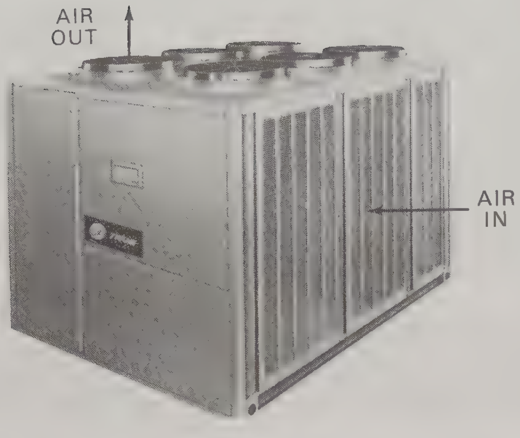
Water-cooled condensers are very efficient, but also present special problems related to water conditions. Lime and scale deposits occur inside the condenser tubing, which tends to insulate the tubing and thus reduce efficiency. These scale deposits can severely restrict or even completely stop water flow. Special water treatment chemicals are usually added to the cooling water to reduce problems and prolong equipment life.

Water-cooled condensers are available in four styles, with the name describing the style: tube-in-a-tube, tube-in-a-shell, tube-in-a-coil, and coil-in-a-shell.

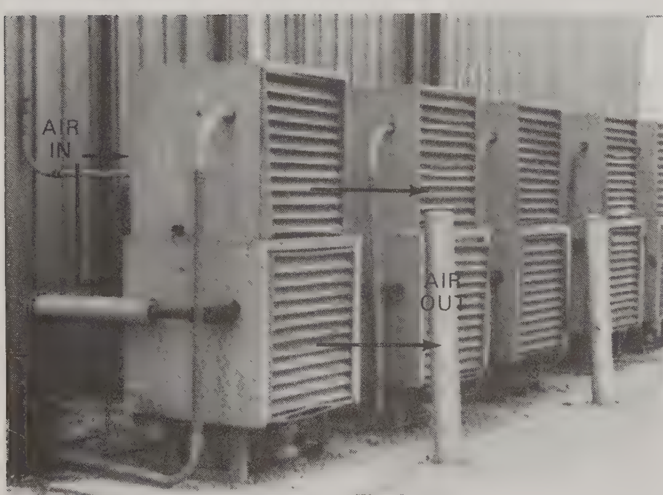
Tube-in-a-tube condenser. The tube-in-a-tube condenser, Fig. 10-25, has one tube located inside another tube. Cooling water circulates through the inside tube and hot discharge gas through the space between the

tubes. The counterflow principle is used for maximum efficiency, meaning that water flows in one direction while the hot gas flows in the opposite direction. The warmest water is next to the warmest refrigerant, and the coolest refrigerant next to the coolest water.

Tube-in-a-shell condenser. This condenser is a cylinder made of steel with copper tubes running from end to end inside it, Fig. 10-26. Water circulates through the

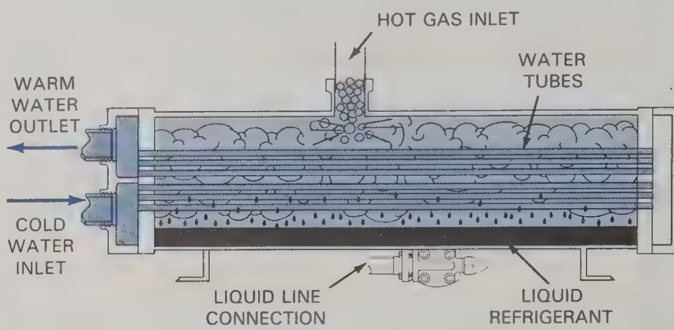


A

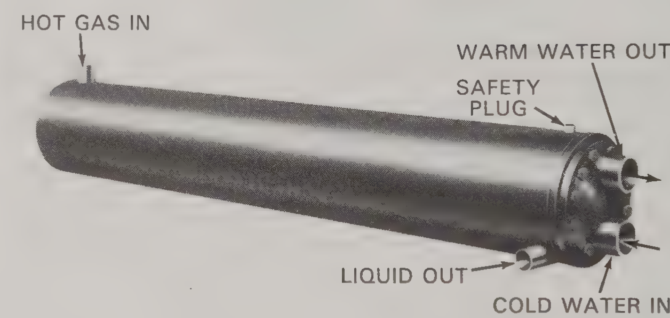


B

Fig. 10-24. Air-cooled commercial condensers. A–A typical unit equipped with several electric fans for forced convection. Ambient cool air is drawn through the side of the unit, and ambient hot air exhausted through the top. (Trane) B–A series of air-cooled condensers at a manufacturing plant. Ambient air is drawn in one side and exhausted out the other.

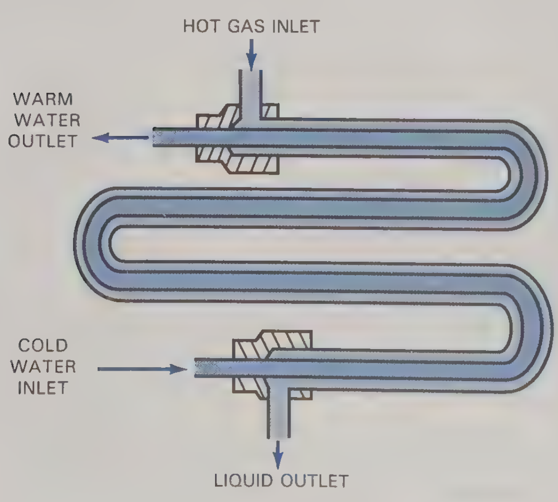


A

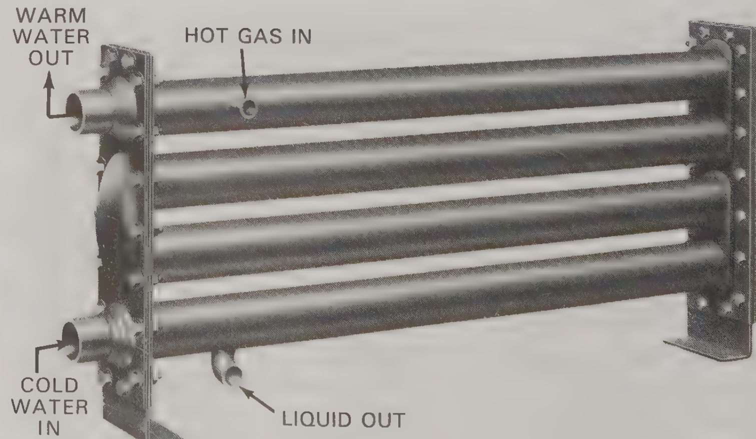


B

Fig. 10-26. Tube-in-a-shell condenser. A–Water flows through the tubes inside the cylinder, absorbing heat from the refrigerant gas and condensing it to a liquid form. B–A typical condenser of the tube-in-a-shell type. (Standard Refrigeration Company)



A



B

Fig. 10-25. Tube-in-a-tube condenser. A–Water flows through the inner tube to absorb heat from the gas that flows in the opposite direction between the two tubes. B–A typical condenser of the tube-in-a-tube type. (Standard Refrigeration Company)

copper tubes and condenses the hot vapors inside the cylinder to a liquid state. The bottom part of the cylinder serves as a storage tank for excess liquid refrigerant.

This condenser has some distinct advantages. It is compact, usually located under the compressor frame, and needs no cooling fan. Water manifolds at each end of the condenser control the flow of water through the copper tubing. When these manifold ends are removed, the water tubes are accessible for easy removal of scale deposits.

Cleaning scale deposits from water-cooled condensers is usually done with a special wire brush attached to a rod that is turned by an electric drill. The brush is run back and forth through the water tubing to remove the scale. Removing the scale deposits may reveal small corrosion pits that penetrate the copper tubing. These pits would permit water to enter the refrigeration system. Cleaning water-cooled condenser tubing is always a gamble.

Tube-in-a-coil and coil-in-a-shell condensers. These types of condensers can only be cleaned with a special acid pump. The pump is used to circulate a special acid through the water tubing to dissolve scale deposits. The system is then flushed with fresh water and placed back into service.

WATER-COOLING TOWER

Water-cooling towers, Fig. 10-27, are commonly used to reduce the operating cost of water-cooled refrigeration systems. The purpose of the ***water-cooling tower*** is to capture the water leaving the condenser and lower its temperature so that it can be recirculated through the condenser for further cooling.

The tower is usually located on a rooftop or other outdoor location where ambient air can be used to cool the water. The hot water leaving the condenser is piped to the top of the tower where a distribution pan or shower heads distribute it evenly through the tower, Fig. 10-28. The falling water droplets must flow through a large chamber that has many rows of metal fins or wooden slats that serve as heat transfer surfaces. The greater the water surface in contact with the air

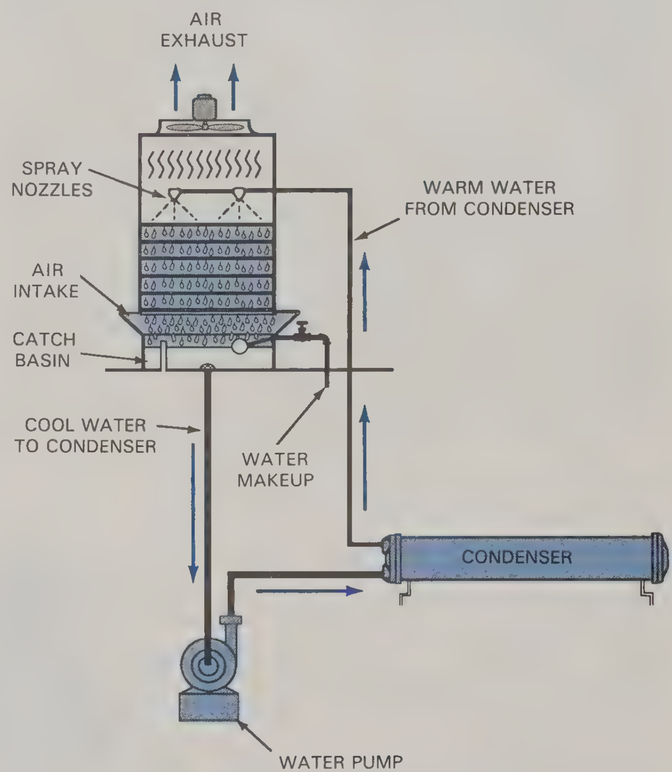


Fig. 10-28. A water-cooling tower removes heat from water and allows it to be recirculated through the refrigerating system condenser again and again to reduce operating costs.

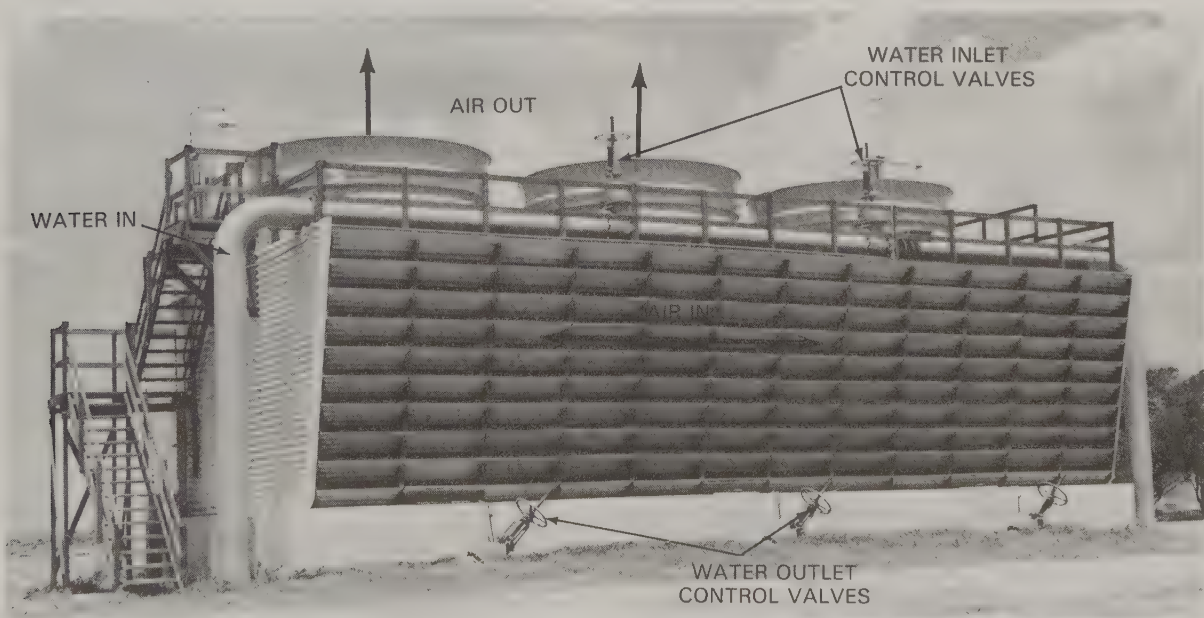


Fig. 10-27. A large cooling tower at an industrial plant. The large valves at ground level control water flow out of the catch basin. (The Marley Cooling Tower Company)

flowing through the chamber, the more efficient the cooling action. A large fan forces ambient air between the slats to cool the water as it falls through the chamber. A catch basin, or reservoir, is provided in the bottom of the tower to collect the cooled water.

The cooled water in the catch basin is re-circulated through the water circuit by a motor-driven water pump. This cooled water first travels to the compressor water jacket, then to the condenser, and back to the tower for re-cooling.

The catch basin also contains a water makeup valve and float assembly to maintain the proper water level in the reservoir. This ***makeup water*** is necessary because some water is lost due to evaporation. Cooling towers evaporate about two gallons of water every hour for each ton of refrigeration.

Sometimes the water reservoir, water pump, and makeup water valve assembly are located inside the building for protection against freezing. The reservoir must be able to hold all the water in the system. A thermostat is used to prevent the water from freezing by turning the tower fan on and off during cold weather. The sensing element for this thermostat is located in the water reservoir.

WATER-REGULATING VALVE

The amount of water traveling through the compressor water jacket and condenser is controlled by a special water-regulating valve located at the inlet to the compressor water jacket, Fig. 10-29. The water-regulating valve is designed to control the head pressure by governing the flow of cooling water to the condenser. A bellows and diaphragm assembly at the bottom of the valve has a capillary tube that is connected to the high-pressure side of the compressor head. This capillary tube transfers the head pressure to the bottom of the water-regulating valve. As the head pressure increases, the valve opens and permits more water flow. Likewise,

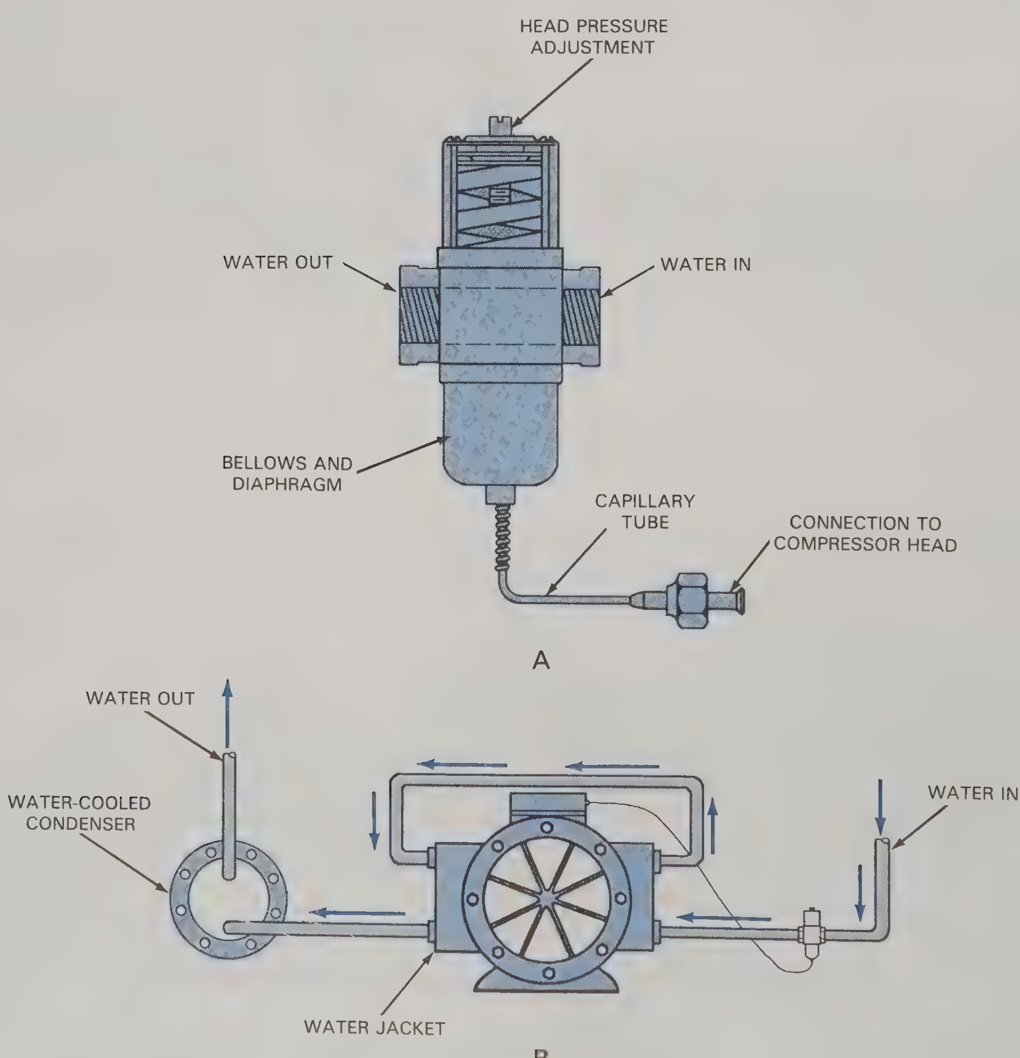


Fig. 10-29. Water regulating valve. A–The valve is located at the inlet of the compressor water jacket, where it controls water flow. B–A capillary tube transmits the compressor head pressure to the bellows and diaphragm of the valve to vary the water flow. As head pressure increases, the valve opens further to increase the flow of water.

as the head pressure decreases, the water flow will decrease.

The spring tension on top of the water-regulating valve is adjustable and permits the technician to control the head pressure at a precise setting. See Fig. 10-30. The water valve will automatically adjust the amount of water flow according to the head pressure, and thus maintains a constant head pressure while the system is running. When the compressor stops, the head pressure falls below the valve setting and the water flow is stopped during the off cycle. The water-regulating valve is very reliable, and once set, seldom requires further attention.

On water-cooled systems, the normal head pressure settings are: R-12 = 115 psig (793 kPa), R-22 and R-502 = 200 psig (1379 kPa). These settings are calculated as a comparison to air-cooled systems operating at an ideal ambient of 70°F (21°C). To check the efficiency of the water-cooled condenser, the head pressure gauge reading should correspond to a temperature of from 10°F to 20°F (5.6°C to 11°C) above the temperature of the water leaving the condenser.

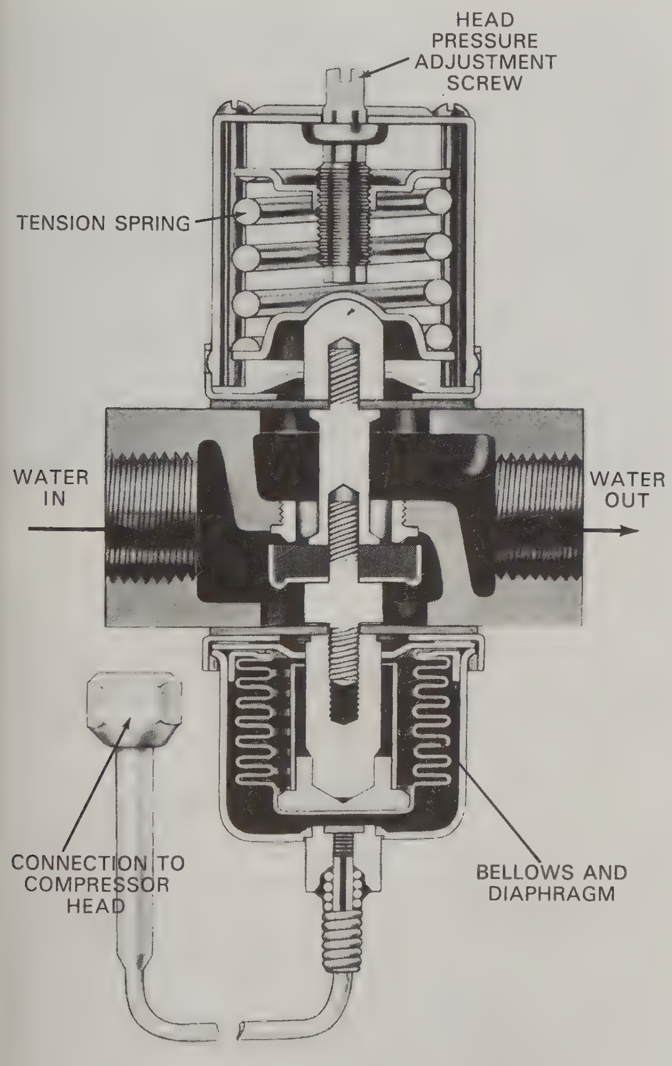


Fig. 10-30. A spring-loaded adjustment at the top of the water-regulating valve permits the technician to precisely control head pressure. (Penn)

SUMMARY

All refrigeration systems are designed to control the movement and condition of the circulating refrigerant. This chapter introduced the basic refrigeration system, the operation of its seven basic components, and the variations that the technician may encounter on different systems. The purpose and operation of each basic component is fully explained, along with the condition of the refrigerant inside each component. Later chapters will introduce other system components and explain how the entire system is controlled. The technician should be able to draw the basic system from memory and state the condition of the refrigerant as it circulates through the system. This knowledge is necessary for recognizing problems, and for understanding later areas of study. Troubleshooting and repair procedures cannot be understood without knowing how and why each component affects the system.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name the seven components that make a basic refrigeration cycle, in order of refrigerant flow. Begin at any point in the cycle.
2. What is the condition of the refrigerant when it is in the evaporator?
3. Name the two division points between the high-pressure and low-pressure sides of the refrigeration system.
4. Describe the function of the component called the refrigerant control.
5. What is the condition of the refrigerant in the suction line?
6. What is the condition of the refrigerant in the hot gas discharge line?
7. Briefly describe the function of the compressor.
8. After air has passed through the condenser, is it hot or cold?
9. After air has passed through the evaporator, is it hot or cold?
10. By controlling the boiling point (pressure) in the evaporator, you also control the __________.
11. What material is used to make the suction and liquid lines?
12. True or false? The suction line is bigger in diameter than the discharge line.
13. In what condition is the refrigerant as it leaves the condenser?
    a. Low-temperature, low-pressure, superheated gas.
    b. Medium temperature, high-pressure liquid.
    c. High-temperature, high-pressure, highly superheated gas.

14. In what condition is the refrigerant as it enters the condenser?
    a. Low-temperature, low-pressure, superheated gas.
    b. Medium temperature, high-pressure liquid.
    c. High-temperature, high-pressure, highly superheated gas.
15. What is the purpose of the evaporator?
16. What is the purpose of the condenser?
17. Name five different styles of evaporators.
18. What is the difference in temperature between the air flowing over the evaporator and the refrigerant inside the evaporator?
19. Which of the following is *not* a type of reciprocating compressor?
    a. Open-type
    b. Semi-hermetic.
    c. Hermetic
    d. Osmotic.
20. List the five types of air-cooled condensers.

Chapter 11

OTHER SYSTEM COMPONENTS

After studying this chapter, you will be able to:
- *Identify condensing units and evaporator sections.*
- *Describe the condition of refrigerant in various accessory components.*
- *Describe the purpose of system accessory components.*
- *Identify component variations.*
- *Name accessory components and describe the purpose of each.*
- *Install and use a gauge manifold.*
- *Discriminate between domestic and commercial systems.*

NEW WORDS

absorb
adsorb
aspirator hole
backseated
charging
condensing unit
cracked
desiccant
dip tube
discharge service valve
evacuating
evaporator unit
filter-drier
frontseated
gauge manifold
heat exchanger
hydrostatic expansion
liquid receiver
liquid receiver service valve
moisture indicator
noncondensibles
overcharge
pig tail
pointer flutter
recalibration
recovery
Schrader valve
sight glass
suction accumulator
suction service valve
undercharge
vacuum pump

EVAPORATING AND CONDENSING UNITS

As described in Chapter 10, the basic refrigeration system consists of seven components: evaporator, suction line, compressor, hot gas discharge line, condenser, liquid line, and refrigerant control.

These components can be further grouped into the *evaporating* and *condensing* units. The larger number of components makes up the ***condensing unit.*** This unit consists of the equipment necessary to reclaim the refrigerant gas and convert it back to a liquid. The condensing unit, Fig. 11-1, contains the compressor, condenser,

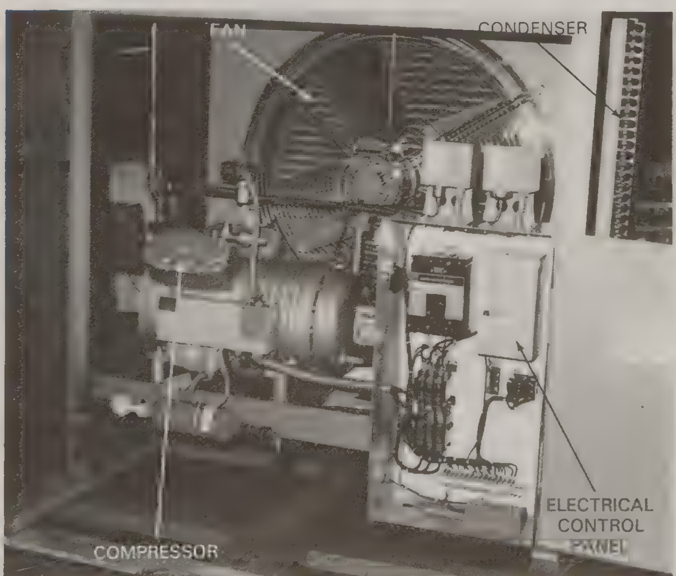


Fig. 11-1. Condensing unit for a commercial installation. It consists of a compressor, condenser, fan, and electrical control panel. The unit may be located a long distance away from the evaporating unit. (Dunham-Bush)

hot gas discharge line, condenser fan, electrical panel box, and some accessory components. The ***evaporator unit*** consists of the evaporator, refrigerant control, evaporator fan, and some accessory components. The suction and liquid lines connect the evaporator unit with the condensing unit to complete the system.

The condensing unit must be somewhere outside the refrigerated space, positioned so that ambient air can be used to cool the condenser. The evaporator absorbs heat from the refrigerated space, while the condenser discharges this heat into the ambient air. These two heat exchangers, therefore, must be well-separated from each other.

The suction and liquid lines connecting the two units may be either long or short. On a domestic refrigerator-freezer, for example, they would be quite short: the evaporator unit is located in the freezer compartment and the condensing unit is below the refrigerator section. See Fig. 11-2. This is called a *self-contained* system, because the condensing and evaporating units are located within the same cabinet.

The remote or *split* system refers to a system in which the condensing and evaporating units are not in the same cabinet. While the evaporator is located inside the area to be cooled, the condensing unit is likely to be on the building's roof or outside at ground level. The condensing unit must be located where the discharged heat is acceptable. The suction and liquid lines connecting the two units may be quite long. A residential central air conditioning system, Fig. 11-3, is an example of a split system. Commercial split systems are essentially the same, but the components are larger.

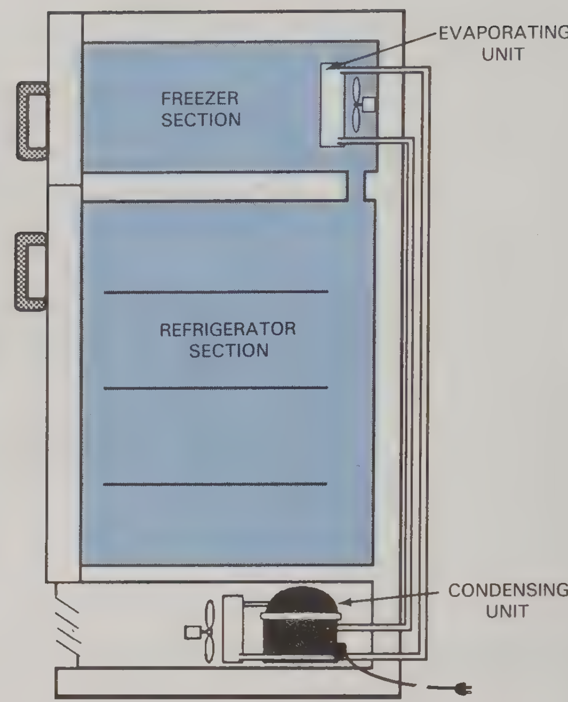


Fig. 11-2. In a self-contained system, the evaporating and condensing units are located inside the same cabinet. Suction and liquid lines are fairly short.

Refrigeration systems are designed to remove heat faster than it leaks into a cabinet or room. The more

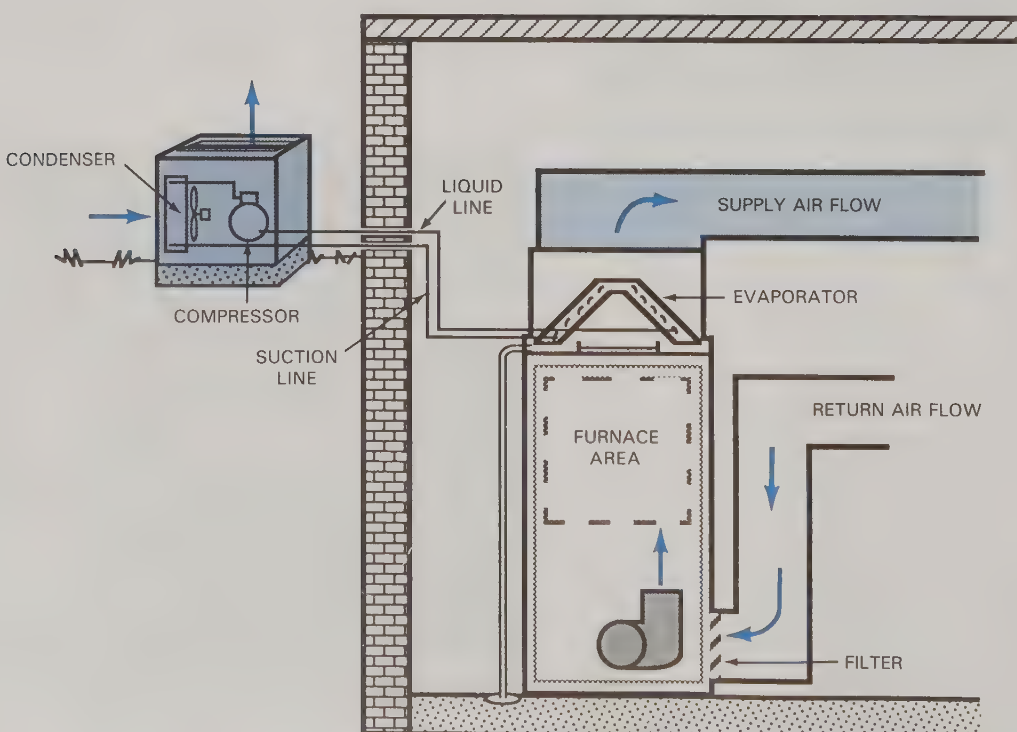


Fig. 11-3. In a split system, like this residential central air conditioning system, the evaporating and condensing units may be located far apart. Long liquid and suction lines connect the inside (evaporating) unit with the outside (condensing) unit.

heat leakage, or load, the bigger the system must be. Other than size, all systems are basically the same. Those that are more complicated-appearing simply have added accessory components to make them more efficient and serviceable.

OTHER SYSTEM COMPONENTS

To understand the operation of any system it is necessary to know how each component operates, and how it affects the system. A malfunction by one component will greatly affect operation of other components. Different components, or combinations of components, are used to make the system more efficient, versatile, and serviceable. It is important to understand the purpose, theory, and operation of these components. Being able to identify these components and know how they function will help you identify the type of system and solve problems.

Many accessory components make it easier to check system operation and perform system repairs. Some components keep the system clean; others provide a means for isolating sections for repairs.

LIQUID RECEIVER

The ***liquid receiver*** is an important accessory in larger systems. It is installed in the liquid line and serves as a storage tank for excess liquid refrigerant. See Fig. 11-4. Ideally, the refrigerant should boil off inside the evaporator at the same rate it is being changed to a liquid state in the condenser. Such a balance is generally achieved in domestic systems, which operate at a fairly steady rate. Larger commercial systems, however, require varying amounts of refrigerant at different times, depending upon the heat load on the evaporator. Therefore, a reserve quantity of refrigerant must be available when needed.

Liquid receivers are not used in domestic refrigeration systems because of cost and because such systems use a capillary tube for the refrigerant control. The amount of refrigerant in these systems is critical. Even a one-half ounce ***overcharge*** (excess of refrigerant) will cause high head pressure because the excess accumulates in the condenser and reduces its capacity.

Commercial systems normally use a thermostatic expansion valve for the refrigerant control, which permits the use of a liquid receiver. (Refrigerant controls are fully explained in Chapter 14) Commercial systems allow for some excess refrigerant; the liquid receiver acts as a storage place for this excess. The amount of refrigerant in a commercial system is not critical, unless it is ***undercharged*** (has insufficient refrigerant).

The commercial systems require larger quantities of refrigerant to operate, so the liquid receiver must be large enough to hold all the refrigerant in the system, plus any excess. All refrigerants are expensive, and this ability to hold the entire refrigerant charge is very desirable when the system must be opened for repairs.

The liquid receiver should be no more than 80 percent full when holding the entire system charge. Since all liquids expand (occupy more space) when heated, the extra capacity allows for liquid expansion within the receiver. The process is called ***hydrostatic expansion.***

The liquid receiver is usually located close to (or below) the condenser. Liquid from the condenser drips into the receiver inlet. As shown in Fig. 11-4, the receiver outlet contains a ***dip tube*** that extends to about one-half inch from the bottom of the receiver. The dip tube ensures that only liquid (no vapor) enters the liquid line at the receiver outlet.

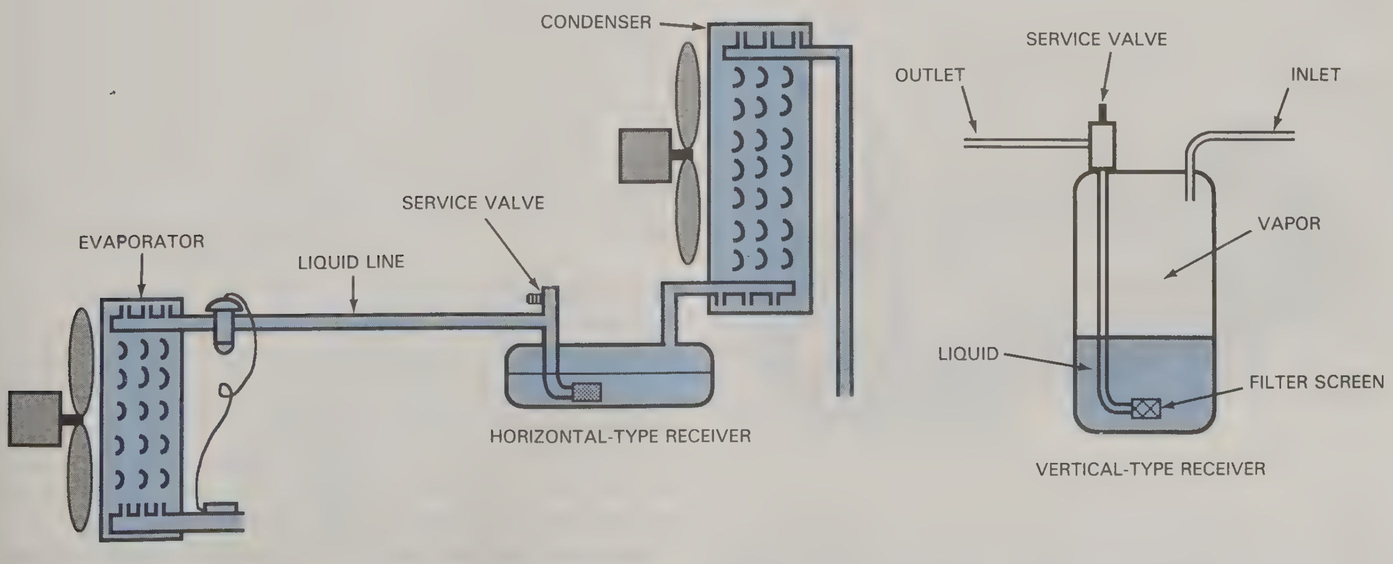


Fig. 11-4. Liquid receivers act as reservoirs for excess liquid refrigerant in larger systems. Receivers are located in the liquid line. Both horizontal and vertical types are used, depending upon the application.

Some large receivers are equipped with two service valves, one at the inlet and one at the outlet. These receivers, Fig. 11-5, also contain a fusible plug and/or pressure relief valve which is used as a safety device. They serve to relieve any sudden increase in pressure to an unsafe level. Such an increase might occur in a fire, for example. The spring-loaded pressure relief valve, Fig. 11-6, will open automatically when a specified pressure is reached in the receiver. The pressure at which the valve will open is adjustable within a given range. The fusible plug, Fig. 11-7, is a relief device designed to melt at a specified temperature. It will release the refrigerant if that temperature (and corresponding unsafe pressure) is ever reached.

Some very large receivers are equipped with a dial-type gauge or with a liquid level sight glass to show how much liquid refrigerant is in the receiver. Liquid level in the receiver should never be more than 80 percent of its capacity, when holding the entire charge of the system.

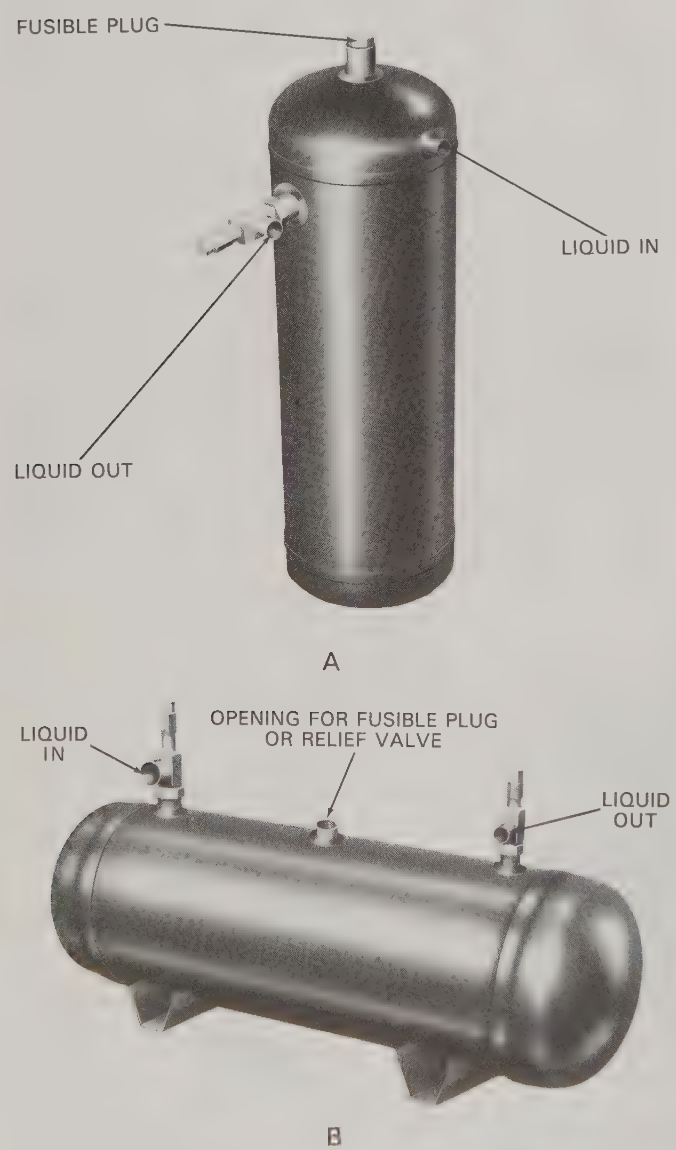


Fig. 11-5. Large liquid receivers with pressure relief devices. A–Vertical receiver with fusible plug installed. B–Horizontal receiver with provision for either fusible plug or relief valve. (Standard Refrigeration Company)

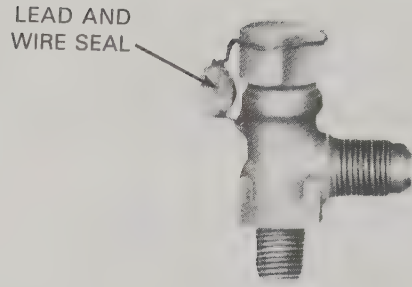


Fig. 11-6. The spring pressure relief valve will open at a specified pressure, then close again when pressure drops below that level. The pressure at which the valve will open is adjustable within a given range. The lead and wire seal prevents any tampering with the valve pressure setting. (Standard Refrigeration Company)

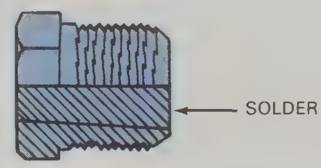


Fig. 11-7. A fusible plug has an opening that is sealed with solder that will melt at a specified temperature (usually 165 °F or 210 °F).

SERVICE VALVES

Service valves are an accessory that serve no operating function, but are indispensable when work must be performed on the system. Service valves are provided on commercial systems for troubleshooting and making repairs. They are not factory-installed on domestic systems, but often are installed by technicians when servicing is needed. The valves make it possible to block off certain sections of the system for service or for reading operating pressures, using the gauge manifold. The *gauge manifold* is a pressure-checking device that has both compound and high-pressure gauges, control valves, and connectors for hoses from the service valves. The service technician must fully understand where service valves are located and how they operate.

Service valve locations

Service valves on commercial systems are normally placed in three strategic locations, Fig. 11-8. The valves provide access for pressure readings, and can be used to control system operation and isolate sections as you attempt to diagnose problems. Failure to use these valves properly may result in wrong diagnoses, excessive service time, and unnecessary loss of refrigerant.

Suction service valve. The ***suction service valve*** (SSV) is located on the low-pressure side of the system, between the compressor and the suction line. Usually,

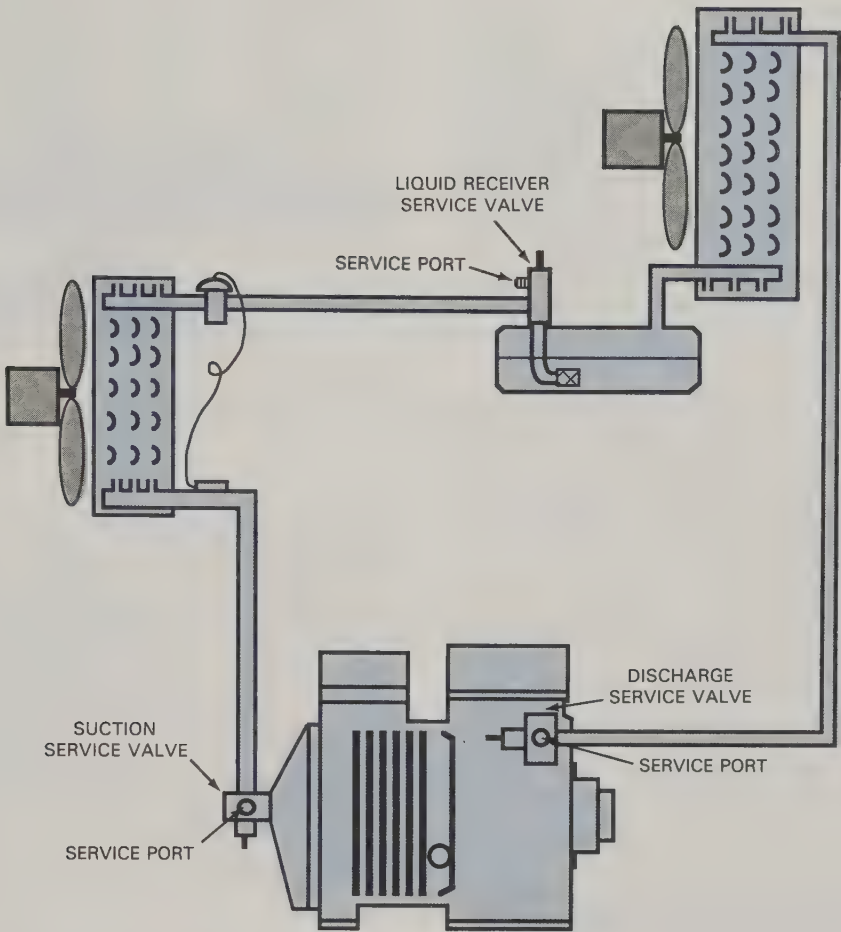


Fig. 11-8. Valves, located at three points in a commercial refrigeration system, permit access to the system for servicing.

the valve is bolted to the compressor and the suction line is then connected to the valve. This location permits the technician to:

- read the system low-side pressure while the compressor is running.
- restrict flow of refrigerant entering the compressor.
- completely stop refrigerant from entering the compressor.

Discharge service valve. The ***discharge service valve*** (DSV) is located on the high-pressure side of the system. Normally, the valve is bolted to the compressor and the hot gas discharge line is connected to the valve. This location permits the technician to:

- read the system high-side pressure while the compressor is running
- restrict flow of gas leaving the compressor.
- completely stop gas from leaving the compressor

Never frontseat (close)this valve while the compressor is running. Discharge pressure will rapidly reach extremely high, unsafe levels.

By placing a service valve on each side of the compressor, it is possible to obtain high- and low-side pressure readings at a single location, the compressor. It also makes it possible to completely isolate, or block off, the compressor (when it is not running) from the rest of the system.

Liquid receiver service valve. The ***liquid receiver service valve*** (LRSV) is located in the liquid line, at the liquid receiver outlet. This valve is welded to the liquid receiver and the liquid line is connected to the valve. This location permits the technician to:

- read the system high-side pressure while the compressor is running
- restrict flow of refrigerant leaving the receiver.
- completely stop liquid refrigerant from leaving the receiver (while the compressor is running).

Some large commercial systems include another service valve located at the liquid receiver *inlet*. This provides a method to isolate the receiver from the rest of the system by closing (frontseating) both receiver valves. This procedure would trap most of the refrigerant inside the liquid receiver.

Service valve ratchet wrenches

Service valves will vary in size, along with the size of the system. This means that the size of the valve stem will vary, as well, making it necessary to have service valve wrenches of different sizes. The ratchet-type wrench

with four sizes of openings, Fig. 11-9, is the most popular because it fits most valve stems and is easily reversed. This tool is a *must* in every technician's tool kit.

Service valve operation

All service valves are designed to function in the same manner, regardless of location, size, or shape. All service valves have three openings, but only two of these openings are controlled by the valve stem. The opening to the compressor (or receiver) is always open. The valve stem controls the inlet (or outlet) and the service port. See Fig. 11-10.

Suction service valve (backseated). With the valve stem in the ***backseated*** position, Fig. 11-11, the refrigerant flow from the suction line to the compressor is unrestricted. The service gauge port is blocked off (closed). This is the normal position of the valve stem when the system is operating.

Suction service valve (cracked). To obtain a pressure reading at the suction service valve, the valve stem must first be in the backseated position to close off the gauge port. You can then remove the cap from the gauge port and connect the blue hose from the compound gauge on the gauge manifold. Next, the service valve stem is ***cracked*** (opened by turning the stem about one or two turns to the right). See Fig. 11-12. This opens the gauge port, and the compound gauge immediately registers the pressure reading.

Cracking the valve open to obtain a pressure reading does not restrict flow of refrigerant to the compressor. This procedure, called "cracking the valve," permits you to read the low side pressure while the system is operating.

Suction service valve (frontseated). When the SSV is ***frontseated*** (valve stem screwed all the way in to the right), the inlet opening is closed off. See Fig. 11-13. This position prevents refrigerant gas from entering the

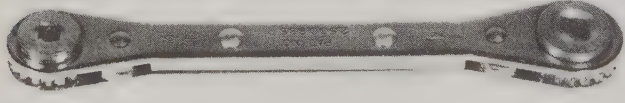


Fig. 11-9. The most popular type of service valve wrench is a ratchet type that has openings of four different sizes. It is easily reversed, as well. (Robinair Mfg. Corp.)

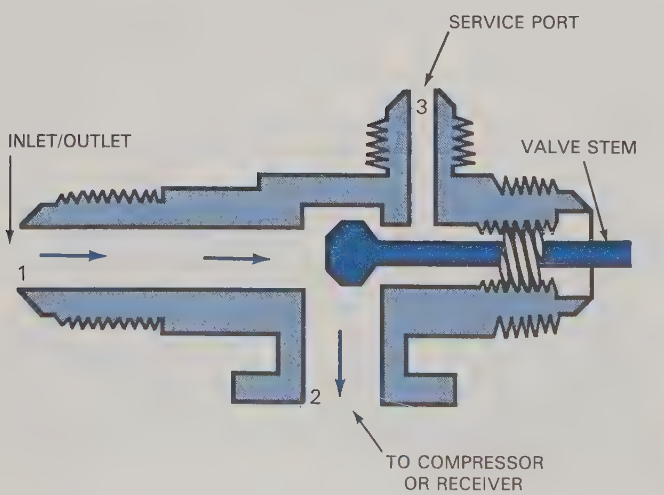


Fig. 11-10. Service valves have three openings: the inlet or outlet (where the refrigerant enters or leaves the valve), the opening to the compressor or liquid receiver, and the service port opening. The valve stem is able to close either the inlet/outlet or the service port, but not the third opening.

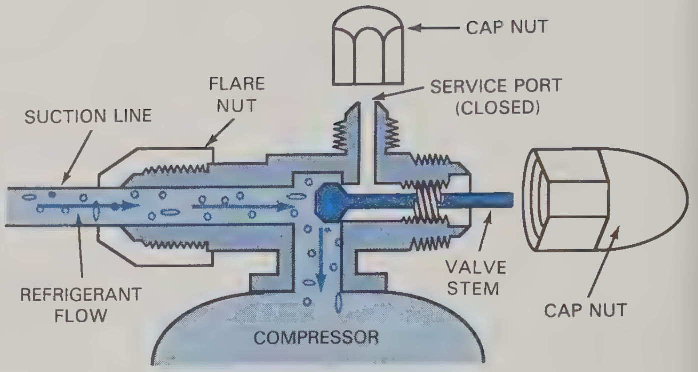


Fig. 11-11. Suction service valve with stem in the backseated position. This is the normal operating position of the valve stem.

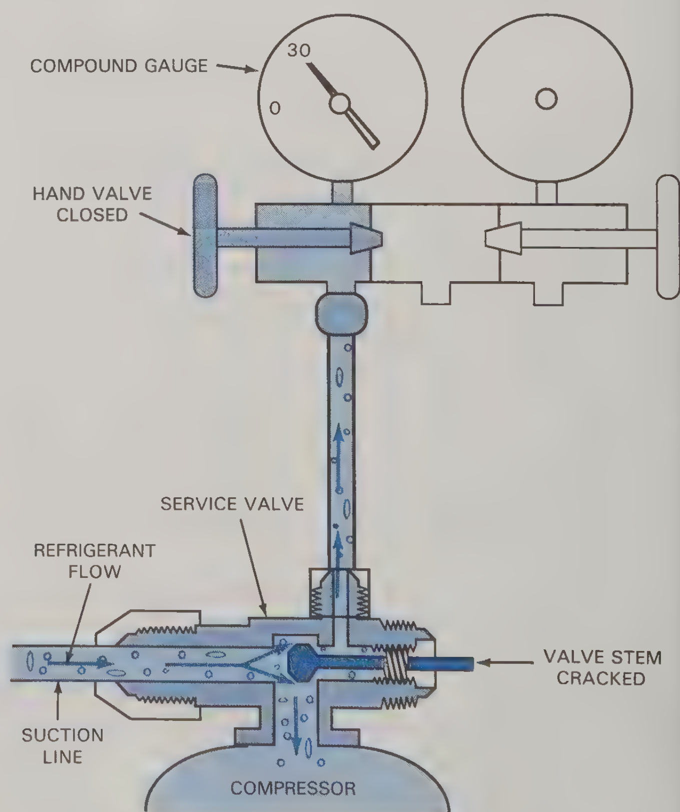


Fig. 11-12. Suction service valve with stem in the "cracked" position. This allows reading the low-side pressure while the system is in operation.

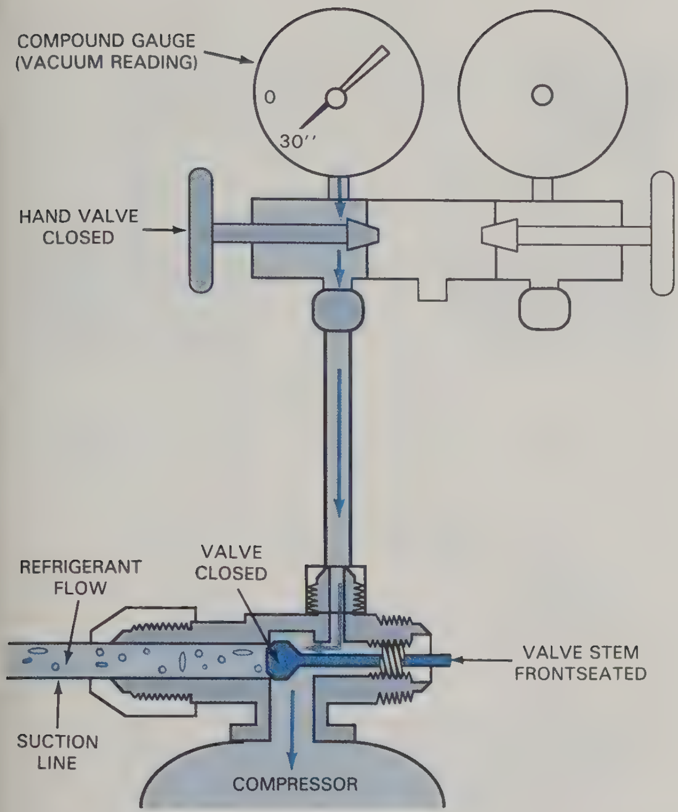


Fig. 11-13. Suction service valve with stem in the frontseated position, permitting a compressor vacuum reading. The inlet is closed, so no refrigerant gas can reach the compressor.

valve. However, the gauge port is open to the compressor. Remember that the compressor opening cannot be closed by the valve stem. The valve stem controls only the gas inlet and the gauge port opening.

If the SSV is frontseated while the compressor is running, the compressor will immediately show a good vacuum on the compound gauge because the suction gas cannot enter the compressor. This procedure is used to check the operation of the compressor. Failure of the compressor to pull a good vacuum when the SSV is frontseated indicates a problem with the compressor valve reeds. Be careful, when the service valve port is open, to avoid allowing the compressor to draw moisture-laden atmospheric air into the system.

Service valves on small commercial units have a built-in 1/4 in. (6.4 mm) male flare fitting at the gauge port (as previously illustrated) for attaching a hose from the gauge manifold. Larger service valves may have one or two openings at the gauge port, plugged with a 1/8 in. (3.1 mm) male pipe plug. To attach the gauge hose to the service valve, remove the plug and install a 1/8 in. (3.1 mm) MPT x 1/4 in. (6.4 mm) MFT half-union, as shown in Fig. 11-14. All technicians keep these half unions readily available.

Discharge service valve operation

Just like the suction service valve, the discharge service valve has three openings and three possible valve stem positions. See Fig. 11-15. However, the DSV controls high-pressure gas *leaving* the compressor, rather than low-pressure gas *entering* the compressor. The opening from the compressor cannot be closed. The gauge port opening is available for the technician to install the red hose from the high-pressure gauge. This makes it possible to obtain a reading of discharge pressure while the system is running.

The valve is backseated for normal operation and when connecting the red hose from the gauge manifold. After connecting the red hose, the valve is cracked open and the discharge pressure is immediately revealed on the high-pressure gauge.

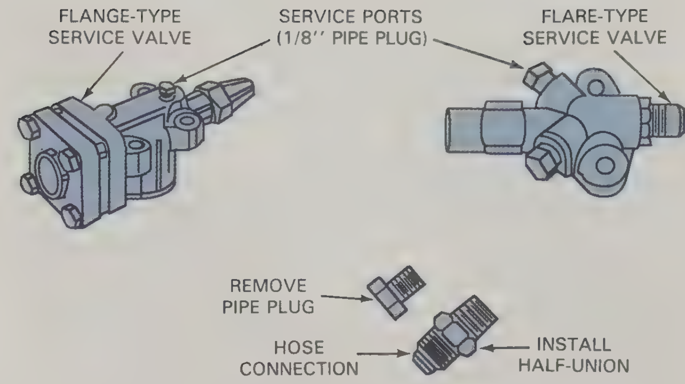


Fig. 11-14. Replacing pipe plugs on valves with half-unions.

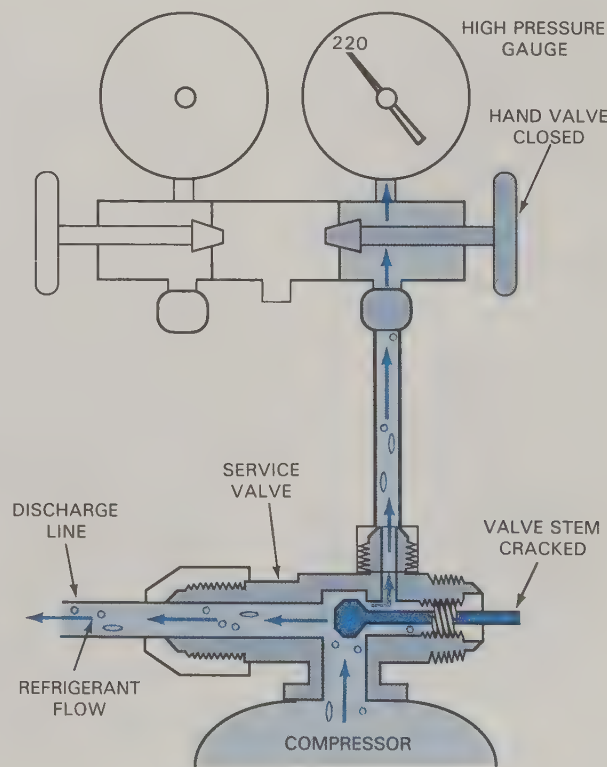


Fig. 11-15. The discharge service valve with the valve stem in the cracked position. This allows reading the discharge (high-side) pressure while the system is in operation.

The discharge service valve should *never* be frontseated (screwed all the way in) when the compressor is running, because this will close the hot gas discharge line. The high pressure gas cannot escape, so very high pressure will develop rapidly in the service valve. This extreme pressure may blow the hose off the valve, or cause the compressor to shut off on a safety control.

If the compressor is shut off for replacement, both the discharge service valve and the suction service valve are both frontseated to isolate the compressor from the system. Both service valves are unbolted from the compressor, the old compressor removed, and the service valves re-bolted to the new compressor after it is installed. This procedure saves the refrigerant in the system, except for the small amount of gas trapped inside the old compressor.

Gaskets are provided with each new compressor for use between the compressor body and the service valves. The old gaskets should be removed with a pocketknife, and mating surfaces cleaned. Be careful not to scratch or cut the mating surfaces. Coat the new gaskets with refrigeration oil before installing them. The oil expands the material slightly so it will be squeezed between the mating surfaces for a leaktight fit.

Liquid receiver service valve

The liquid receiver service valve is welded or screwed into the receiver outlet, and the liquid line connected to it with a flare nut. This service valve operates just like the suction and discharge valves, except that it controls the liquid leaving the receiver. As shown in Fig. 11-16, the valve is backseated during normal operation. The valve can be cracked to read high-side pressures at the receiver valve, or frontseated to completely stop liquid refrigerant from leaving the receiver.

Pumping the system down. It is often necessary for the technician to manually "pump the system down." This means to remove all refrigerant from the low-pressure side and pump it over to the high-pressure side of the system. This is done by frontseating the liquid receiver service valve while the system is running. The compressor will remove refrigerant from the low-pressure side of the system all the way back to that valve. The compressor is then turned off. The valve reeds inside the compressor head should prevent refrigerant gas from flowing back into the low-pressure side of the system. If necessary, the suction service valve can be frontseated after the system is pumped down.

Whenever a system is pumped down, its low-pressure side is usually in a good vacuum. The system should not be opened while in a vacuum, because moisture-laden atmospheric air would rush into it. A vacuum pump would then have to be used to remove these unwanted gases.

Liquid receiver with two service valves. Larger liquid receivers will sometimes have two service valves, one at the inlet and one at the outlet of the receiver, Fig. 11-17.

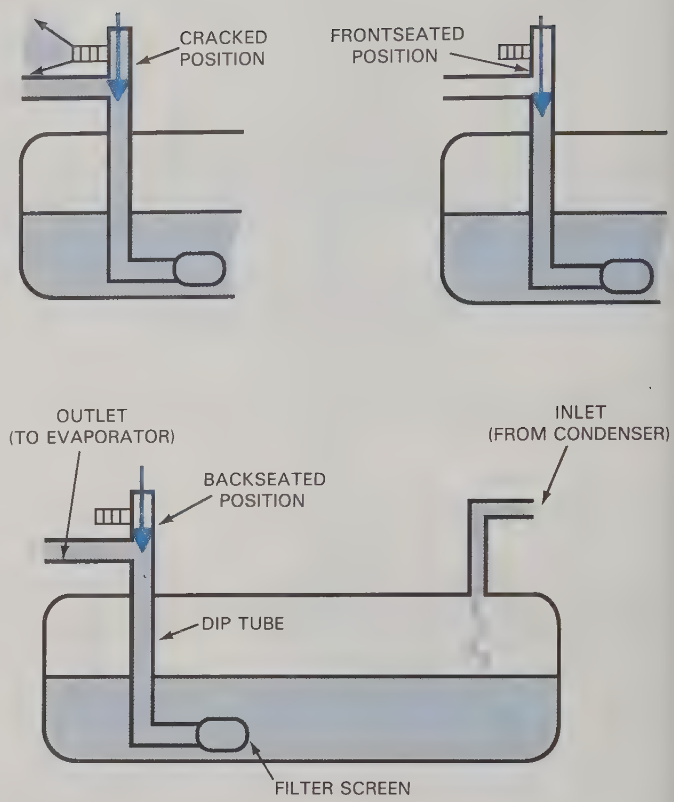


Fig. 11-16. The liquid receiver service valve is cracked to obtain a pressure reading, and frontseated to pump the system down. It is backseated for normal operation.

This makes it possible to pump the system down, then frontseat both receiver valves. This procedure isolates the liquid receiver, which would then contain most of the refrigerant in the system (some gas would remain in the condenser and hot gas discharge line). This procedure would be used when it is necessary to make repairs to the condenser, for example. Pumping the system down will save most of the refrigerant.

The service valve on the inlet to the receiver also makes it easy to purge air from the receiver. Whenever

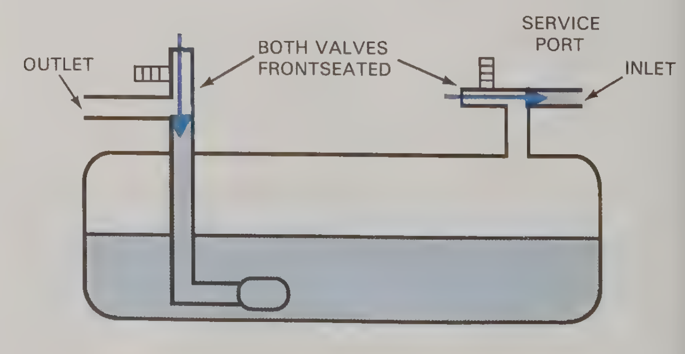


Fig. 11-17. Service valves at both the inlet and outlet of the liquid receiver allow isolation of the receiver. Most of the system's refrigerant, in liquid form, can be trapped there. Noncondensibles can be purged through the service port of the inlet valve.

atmospheric air enters the system, it will become trapped in the liquid receiver. Atmospheric air is considered to be noncondensible and will remain a gas as it travels through the condenser. Therefore, it will become trapped in the top of the liquid receiver.

The technician can remove these ***noncondensibles*** by turning the system off and frontseating the receiver inlet valve. This blocks off the valve inlet and opens the service port to the top of the receiver. The noncondensibles now can be removed through the service port. This procedure requires the use of a refrigerant recovery device until all noncondensibles are removed from the receiver and the head pressure returns to normal.

Service valves for domestic systems

Manufacturers of domestic systems, such as refrigerators and freezers seldom have factory-installed service valves. These systems are totally hermetic (sealed systems); the service technician must install service valves as needed. There are two basic types of valves installed by technicians: clamp-on valves and core-type valves.

Clamp-on valves. These valves are known by various names (saddle valve, line-piercing valve, and so on), but all are used in the same way: they straddle the tubing and clamp into place, then use a needle point to puncture a hole in the tubing. See Fig. 11-18. Gaskets and seals inside the valve act to prevent refrigerant from leaking around the needle hole. The valve provides an access port for attaching a hose from the gauge manifold.

Once these clamp-on valves are installed on the suction and/or hot gas discharge lines, they become a permanent addition to the system. They also become a future source of problems, due to possible leakage at the needle hole. These valves should only be used for troubleshooting one of two problems:

- The compressor runs but does not compress properly.
- The system is entirely out of refrigerant due to a leak.

The pressures indicated on the gauge manifold will reveal which of these two problems exists. If the gauges reveal the *same pressure* on each side of the system, the compressor is defective (has bad valve reeds) and must be replaced. If the gauges reveal *no pressure* on either side of the system, the unit has a leak and lost all refrigerant.

Each of these problems will involve expensive repair procedures that require breaking into the hermetic system. The tube piercing saddle valves are used for diagnosis only, and should be replaced by Schrader (core-type) valves if repairs are authorized.

Schrader (core-type) valves. The recommended procedure for breaking into and resealing a hermetic system is by installing a ***Schrader valve.*** See Fig. 11-19. Most hermetic compressors are factory equipped with an extra copper tube (a ***pig tail***) that gives access to the suction pressure inside the hermetic shell. A Schrader valve is easily brazed to the end of this pig tail.

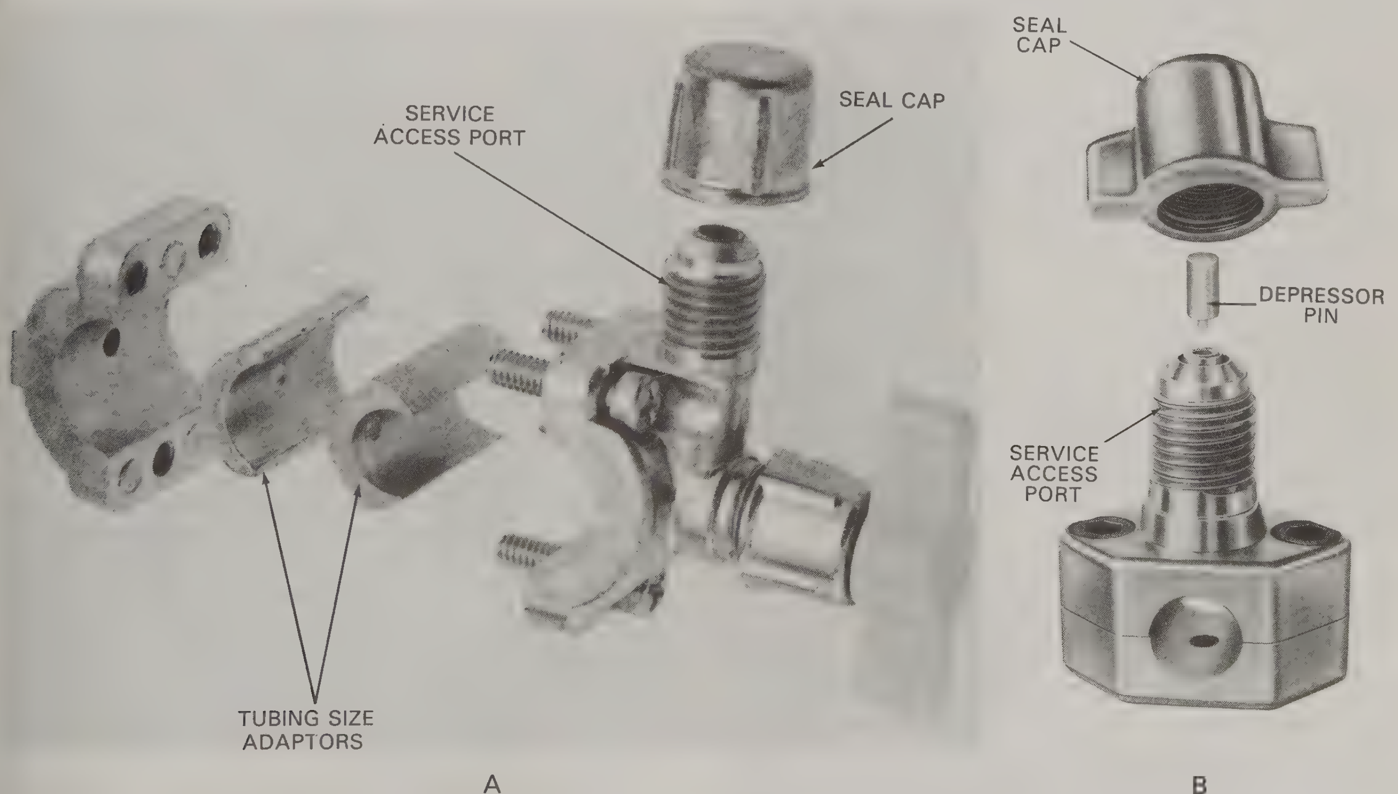


Fig. 11-18. Saddle valves. A–Valve is clamped over tubing to provide an access port for diagnosing system problems. Adaptors permit use on different tubing sizes. B–Depressor pin punctures tubing when cap is tightened. The pin is then removed and the cap used to seal the access port.

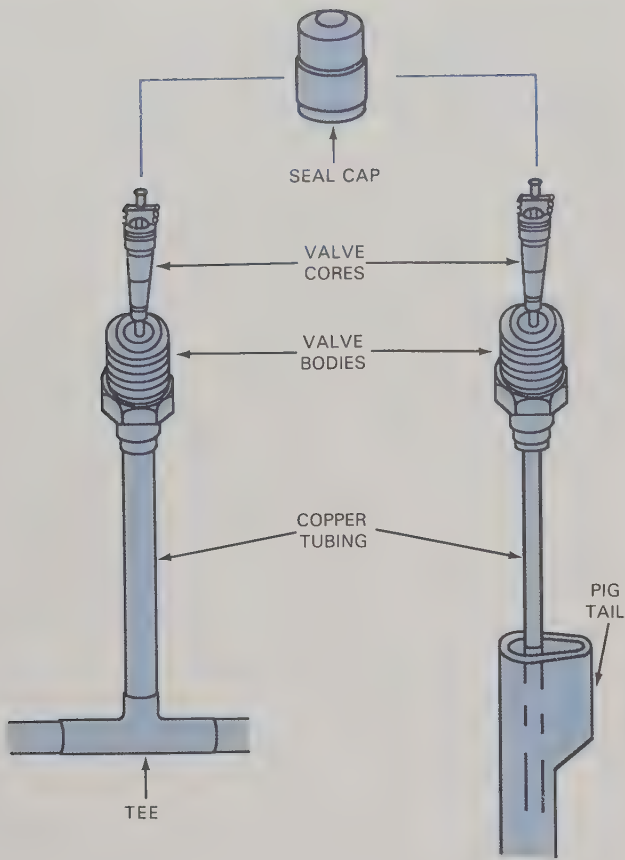


Fig. 11-19. Schrader valves are installed for permanent service access to domestic systems. The cores must be removed while the valve body is brazed to the tubing, since heat would affect the gasket material.

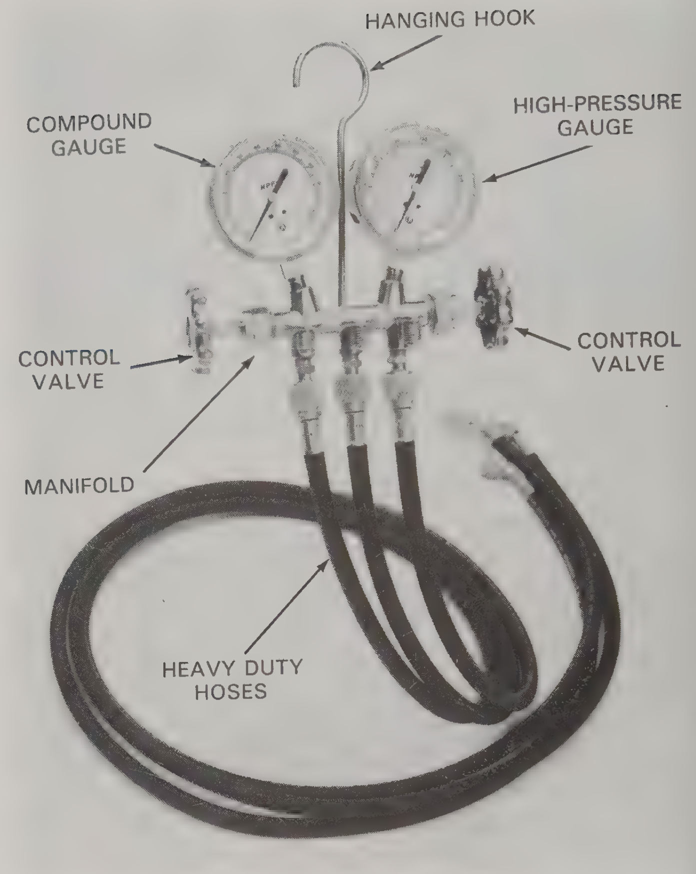


Fig. 11-20. The gauge manifold is the technician's basic testing tool for determining system pressures. It is equipped with two gauges, control valves, and connection hoses. (Uniweld)

Access to the high pressure side is usually more difficult because the hot gas discharge line must be cut and a wrought copper tee installed to provide an opening for installing a valve. The valve is brazed to the branch opening on the tee.

Schrader valves have cores similar to those used on automobile tires. However, because of the special gaskets used, the valve core must be removed prior to brazing. It can be replaced after the joint has cooled. The hoses on the gauge manifold have a built-in device to depress the core when the hose is connected to the valve.

The seal cap for a core valve contains a rubber gasket to help prevent leaks. This cap should *always* be installed when the valve is not in use.

THE GAUGE MANIFOLD

The gauge manifold is the technician's most valuable tool because it is used to determine the operating characteristics inside the system. The gauge manifold, as noted in an earlier section, is a pressure-checking device with both compound and high-pressure gauges. See Fig. 11-20. It also has control valves, and connectors for hoses to the service valves. The gauges will reveal the system's operating pressures, the information that helps the technician determine what repairs are needed. The manifold is also used while performing the repairs.

Learning how to use the gauge manifold properly will save you countless hours in diagnosing field problems, determining what is causing them, and deciding how to solve them. Without the gauge manifold, it is virtually impossible to identify system problems. It is recommended that the service technician become thoroughly familiar with the manifold and its many uses.

PRESSURE GAUGES

The gauge manifold has two gauges for a wide range of possible readings Fig. 11-21. The compound gauge is designed for connection to the low-pressure side of the refrigeration system. It has scales to show pressure readings from 0 psig to above 120 psig, and vacuum from 0 in. Hg to 30 in. Hg. The high-pressure gauge is designed for connection to the high-pressure side of the refrigeration system, and shows only pressure readings (0 psig to 500 psig, typically).

The rapid compression strokes of the pistons will sometimes create pressure pulsations that cause the gauge pointer to swing above and below the actual pressure reading. This is called ***pointer flutter.*** The correct

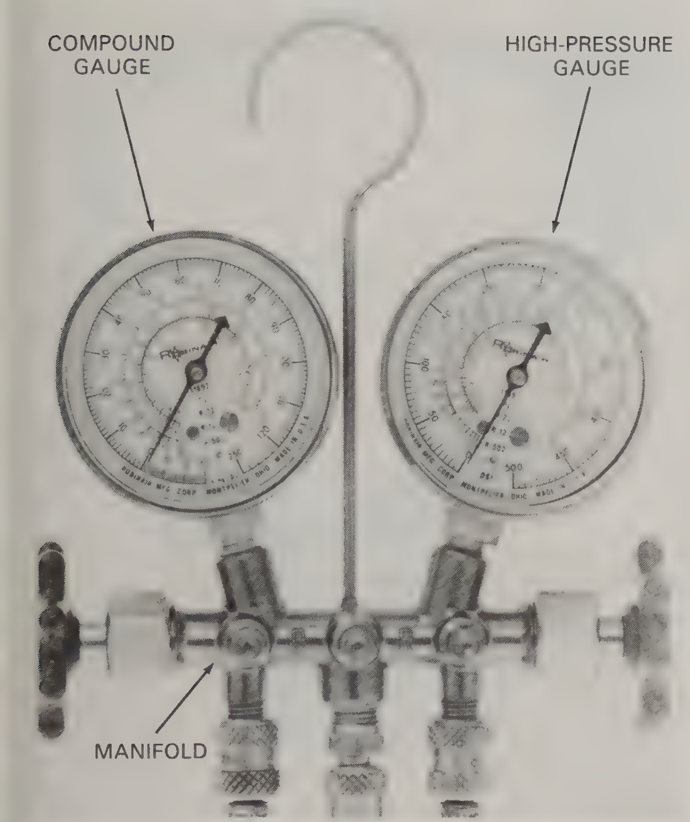


Fig. 11-21. The compound gauge is used for both pressure and vacuum readings, while the high-pressure gauge is used only for pressure readings. (Robinair Mfg. Corp.)

pressure reading is obtained at the center of the flutter. Special pressure gauges, Fig. 11-22, are available with a built-in pulsation dampener to prevent pointer flutter.

The temperature-pressure relationship for each of the three most popular refrigerants (R-12, R-22, and R-502), is included on the dial face of refrigeration gauges. The outside scale (black numbers) indicates pressure. The three inner scales (red numbers) indicate Fahrenheit temperatures that correspond with the pressures for each of the three refrigerants. Simply follow the line of the needle to the proper temperature scale to determine the temperature that corresponds with the pressure reading.

It must be remembered that refrigeration gauges will only reveal saturation temperature for a given pressure. The gauges will *not* reveal superheat (temperature above saturation), or subcooling (temperature below saturation). A thermometer must be used to determine the temperature difference between saturation and superheat (or subcooling).

For efficient operation of the system, the amount of superheat or subcooling at various points must be determined and controlled. For example, a pressure reading at the suction service valve may be 14 psig and this corresponds to 9°F (-13°C) saturation temperature. However, if a thermometer is clamped to the suction line at the entrance to the suction service valve, the reading would be about 24°F (-4°C). The difference in temperature readings amounts to 15°F (24 - 9 = 15). Therefore, the refrigerant contains 15°F (8°C) of superheat as it enters the suction service valve.

Recalibrating gauges

Refrigeration gauges are sensitive instruments and are initially calibrated to produce accurate readings. While these gauges will withstand some abuse, they should be handled with care. It is not unusual for the gauges to require ***recalibration*** in the field due to use and handling.

The clear crystal face on the gauge must be unscrewed, as shown in Fig. 11-23, to gain access to the recalibration screw. This screw is on the gauge face, usually just below the needle hub. The hose on the manifold body immediately beneath the gauge is removed to expose the inlet port to atmospheric pressure. A suitable screwdriver is then used to slowly turn the recalibration screw until the pointer lines up with zero (atmospheric).

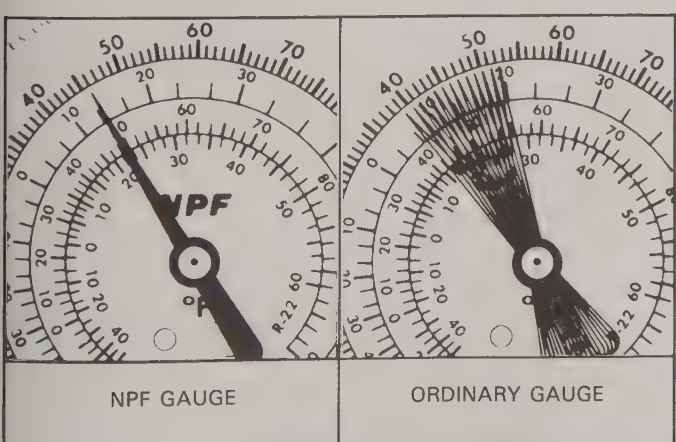


Fig. 11-22. A special gauge with pulsation dampener eliminates pointer flutter, making possible more accurate readings. (Uniweld)

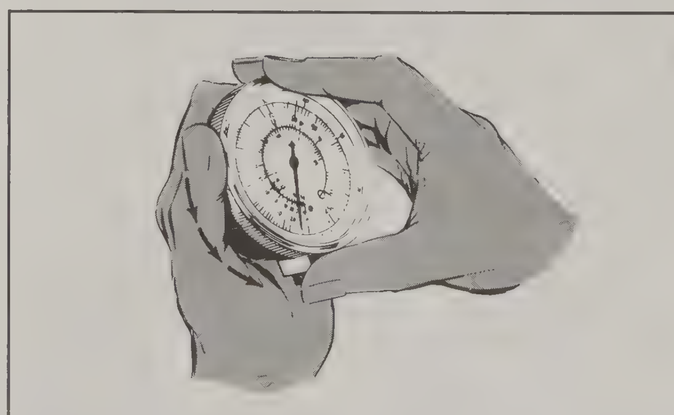


Fig. 11-23. Unscrewing the clear crystal of the gauge to reach the recalibration screw on the dial face. For accurate readings, gauges must be periodically recalibrated, or *zeroed*. (Imperial Eastman)

MANIFOLD BODY

The compound gauge and the high-pressure gauge are directly connected to the hose connections by special bypass gas passages through the manifold body. A hose connection is located directly beneath each gauge. The gas passage between each gauge and its connecting hose is *never closed.* See Fig. 11-24. The two hand valves located at each end of the manifold are used to control access to the middle hose only. These valves *do not* control the bypass gas passages to the gauges.

The center hose is used for adding refrigerant to a system (***charging***), removing refrigerant from a system (***recovery***), or emptying a system with a vacuum pump *(**evacuating**)*. Each of these procedures require the proper pattern of opening the hand valves to gain access to the center hose. Both valves are normally closed and should be opened only when access to the center hose is needed.

The left-hand valve controls access to the center hose via the low-pressure side; the right-hand valve, via the high-pressure side. Opening both hand valves will open the center hose to both gauges.

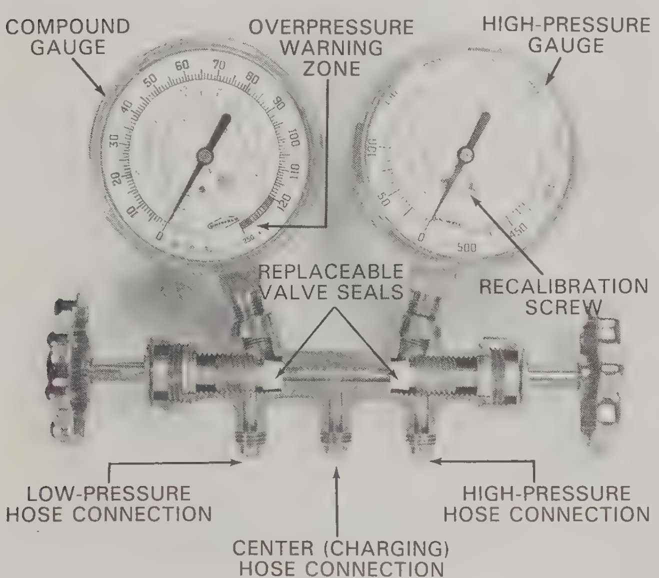


Fig. 11-24. Cross section of the gauge manifold body. The hand valves are used only to allow access to the center hose. (Uniweld)

REFRIGERATION HOSES

Refrigeration hoses are made to withstand working pressures of 500 psig to 750 psig (3448 kPa to 5171 kPa). The hoses are normally color-coded: *blue* for low pressure, *red* for high pressure, and *yellow* for the center connection. These hoses are made to remain flexible under most temperature conditions for easy handling. Each hose has a straight connector at one end and an angled (45°) connector at the other, Fig. 11-25. The straight ends connect to the 1/4″ flare fittings on the manifold body. The long angled ends are designed to provide easy fingertight connection to the proper service valve. They include a valve-core depressor for connection to Schrader core-type valves.

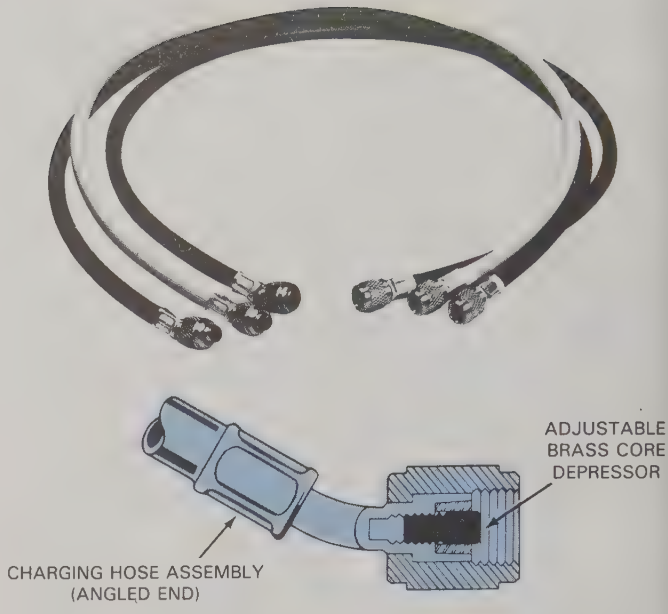


Fig. 11-25. Refrigeration hose is designed to withstand high pressures and temperature extremes. The straight connector attaches to the manifold body; the angled connector to the service valve or Schrader valve.

A special gasket inside the angled hose end is designed to provide a leaktight seal on the service valve or Schrader valve with only fingertight pressure. This gasket can become badly worn due to long use or abuse, but is easily replaced. Replacement gaskets are available from your local supplier. Before fully tightening refrigerant hoses, purge them of air by allowing a small amount of refrigerant to escape through them.

PURGING AND VENTING

Purging and *venting* are terms used to describe the process of releasing refrigerant to the atmosphere. Older repair procedures involved purging or venting with refrigerant to sweep atmospheric air from hoses or tubing. Because of damage to the ozone layer caused by release of CFC refrigerants, the release of these refrigerants is no longer acceptable. A federal law effective in 1992, establishes criminal penalties for knowingly and negligently releasing R-12 and certain other halide refrigerants to the atmosphere. When installing or servicing refrigeration units, proper use of vacuum pumps or refrigerant recovery units is necessary. Such units, and procedures for using them, are discussed more fully in later chapters.

EVACUATING THE SYSTEM

Evacuation is a term used to describe the procedure used to clean the system prior to charging. The proce-

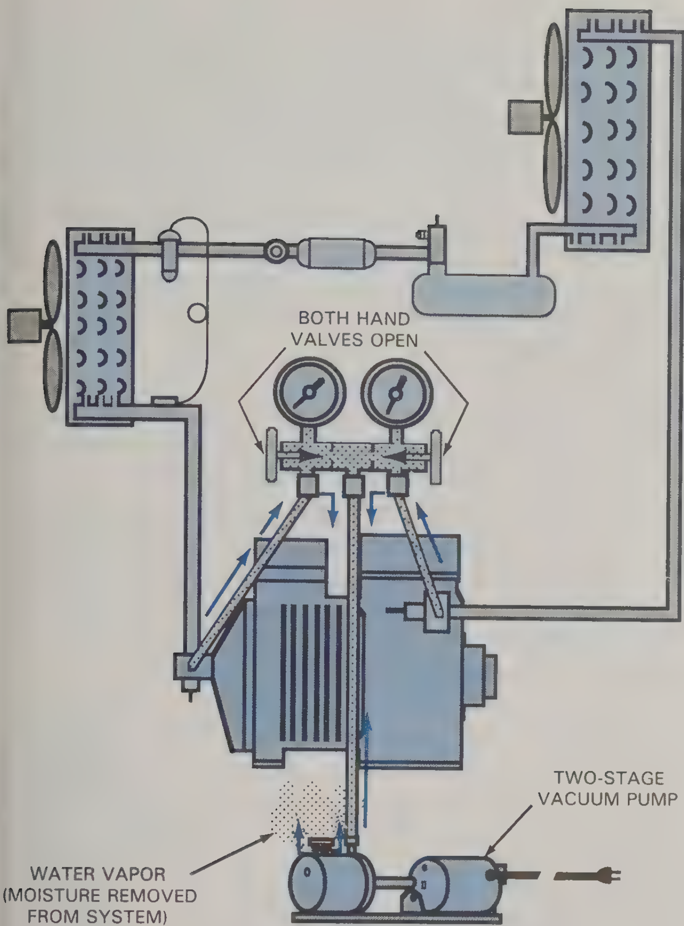
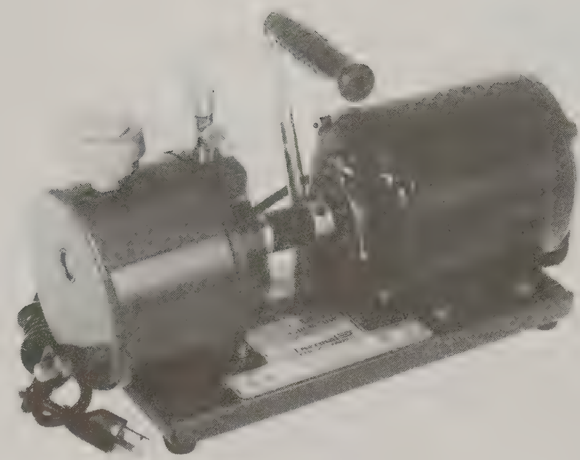


Fig. 11-26. Typical arrangement for evacuating a refrigeration system. The two-stage vacuum pump reduces system pressure far enough to vaporize and draw off any moisture.

dure involves using a ***vacuum pump*** to remove all gas and moisture from the system. Fig. 11-26 shows the arrangement used for evacuating a system, with the yellow hose connected to a two-stage vacuum pump.

The vacuum pump removes moisture from the system by reducing pressure so that any moisture will boil (vaporize) at normal atmospheric temperatures. In a perfect vacuum, water will change state to a vapor at -90°F (-68°C). Water vapor is drawn out of the system by the vacuum pump.

A two-stage vacuum pump, Fig. 11-27, is necessary to reduce the pressure sufficiently and hold it at that level long enough to allow the moisture to vaporize and be removed as a gas. A two-stage pump features a second pumping chamber to enable the pump to obtain a lower vacuum, Fig. 11-28. In such a pump, the exhaust of the first pumping stage is discharged into the intake of the second pumping stage, rather than to the atmosphere. The second stage begins pumping at a lower pressure and, therefore, pulls a deeper vacuum on the system than the first stage could do by itself. Two-stage vacuum pumps are capable of pulling down to an extremely low vacuum, but will seldom do so under field conditions. The two-stage vacuum pumps are able to



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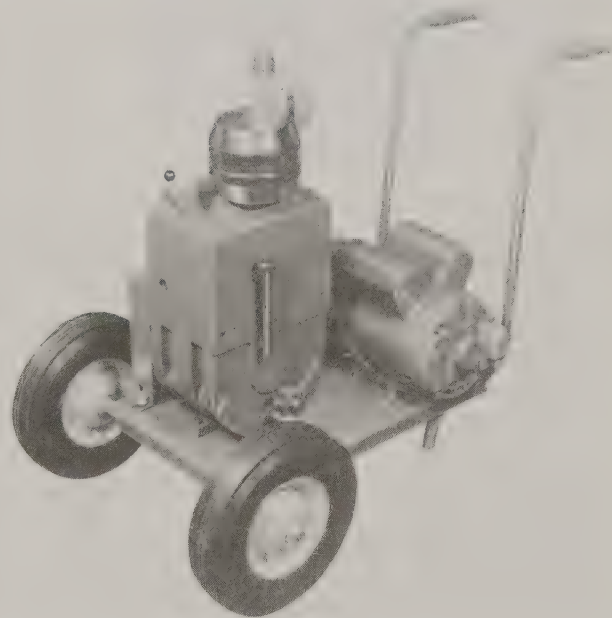


B

Fig. 11-27. Two-stage vacuum pumps are available in different sizes for varying applications. A–A small 1.6 cfm pump (Thermal Engineering). B–A cart-mounted 15 cfm unit for use on large systems. (Robinair Mfg. Corp.)

reach and hold a low vacuum for prolonged periods of time.

Evacuation procedure

1. Connect the red and blue hoses on the gauge manifold to the appropriate service valves. Crack open the service valves and close the manifold hand valves.
2. Connect the center (yellow) hose to a two-stage vacuum pump and start the pump. Very slowly crack open both manifold hand valves. Be careful to avoid drawing oil out with the vacuum pump. After one or two minutes, the compound gauge

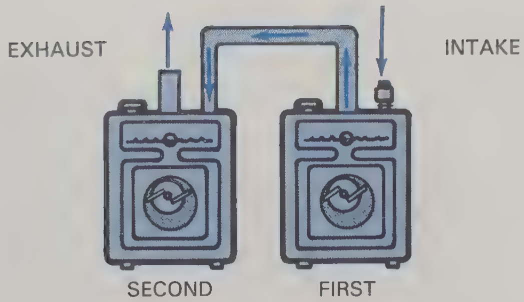


Fig. 11-28. Output of the first stage becomes the input for the second stage, allowing the two-stage pump to obtain a lower vacuum than would be possible in a single-stage pump. (Robinair Mfg. Corp.)

should read 15 in. Hg (15 inches vacuum). You can then fully open both manifold valves. The vacuum pump should quickly reduce the system pressure to about 29 or 30 in. Hg. If the pump fails to pull an adequate vacuum, there is probably a leak in the system, that must be found and corrected. After reaching a vacuum of 29 or 30 in. Hg, permit the vacuum pump to operate for at least *one-half hour*. You must allow adequate time for any moisture to vaporize, and for any refrigerant gas that mixed with oil in the compressor crankcase to be evacuated. Larger systems will require more time on the vacuum pump.

3. *Before* shutting off the vacuum pump, close both manifold hand valves. Shut down the pump, then remove the yellow hose. The refrigeration system is now in a deep vacuum, because all gases have been removed by the vacuum pump. The system should hold this vacuum unless a leak permits atmospheric air to enter (or the vacuum pump was not connected to the system long enough).

Leak detection. Closing the manifold valves and waiting to see if the system loses its vacuum is *not* a proper leak detection method. The vacuum pump may have been stopped too early for proper evacuation, or the leak may be too small for atmospheric air to enter. Even with a perfect vacuum, the pressure differential between the inside and outside of the tubing is only 15 psi (103 kPa). It is poor procedure to leak test with such a low pressure differential. Most leak detection is accomplished with pressures of 200 to 300 psi (1379 to 2069 kPa) because the refrigerant molecules are much smaller than air molecules. Various leak detection methods are discussed in Chapter 13.

CHARGING THE SYSTEM

WARNING: During compressor operation, the pressure in the high-pressure side of the system will be higher than the pressure in the refrigerant cylinder. If the manifold hand valve on the right (high-pressure) side is accidentally opened, refrigerant will be pumped back into the cylinder. This could cause dangerous overpressure in the cylinder and could rupture it. *Always feed the refrigerant charge into the low-pressure side of the system and always feed refrigerant as a gas, not a liquid.*

The gauge manifold arrangement used for charging a system is shown in Fig. 11-29. *Charging is done with the system operating.* Follow this procedure:

1. Close both manifold hand valves. Check gauge pointers for accuracy of zero reading. Recalibrate if necessary.
2. Connect the low-pressure (blue) compound gauge hose to the suction service valve. Tighten it finger-tight. Crack open the service valve.
3. Connect the high-pressure (red) gauge hose to the discharge service valve, tightening it finger-tight. Crack open the *service* valve. (Remember that the high-pressure *manifold hand valve* must remain **closed.**)

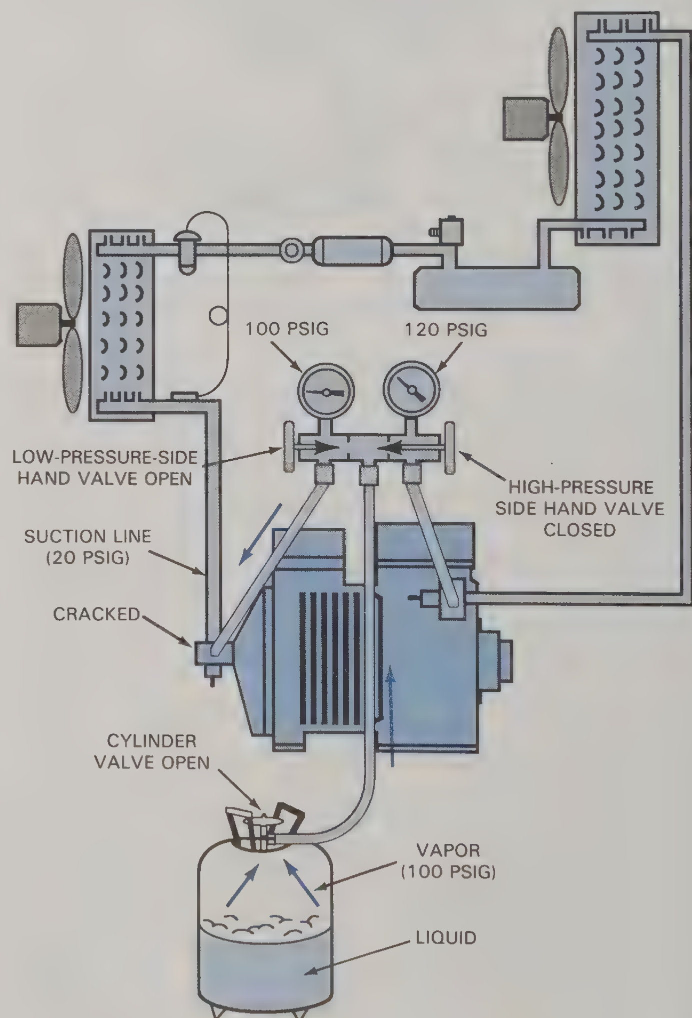


Fig. 11-29. Typical arrangement for charging a refrigeration system. The refrigerant cylinder pressure must be greater than the pressure in the suction line, so that refrigerant will be forced into the system.

4. Connect the center (yellow) charging hose to the refrigerant cylinder. Make sure that the container is in upright position, so you will obtain gas, not liquid. Never charge liquid refrigerant into a system; it will damage compressor valve reeds or remove oil from bearings.
5. Fully open the valve on the refrigerant cylinder. This transfers control to the gauge manifold.
6. With the system running, slowly open the left (low-pressure) side manifold hand valve. The pressure inside the refrigerant cylinder is higher than the low-side system pressure, so the gaseous refrigerant will be forced up through the center hose, through the left side of the manifold, into the blue hose and then, into the system. For safety, the manifold valve on the right (high- pressure) side must remain closed during the charging procedure.
7. To observe the changing conditions of the low-side system pressure, occasionally close the left-side manifold valve and check the compound gauge. Also closely watch the high-pressure gauge during the charging procedure. Continue adding refrigerant to the system until both high and low pressures achieve normal status.
8. Backseat (close) both service valves and close the valve on the refrigerant cylinder. Purge all three gauge hoses. Disconnect the hoses from the service valves and screw hose ends onto the "dummy" fittings at the manifold. Replace covers or caps on the service valves.

FILTER-DRIERS

Regardless of the care used in evacuating and charging a system, it is safe to assume that the system is not completely free of moisture. Installing a ***filter-drier*** in the system, Fig. 11-30, will absorb the remaining moisture. It will also catch any foreign particles that are circulating with the refrigerant.

On commercial systems the filter-drier is normally installed in the liquid line, immediately after the liquid receiver. A second unit may be installed in the suction line, as well, as shown in Fig. 11-31. On domestic systems, the filter-drier is typically located at the condenser outlet.

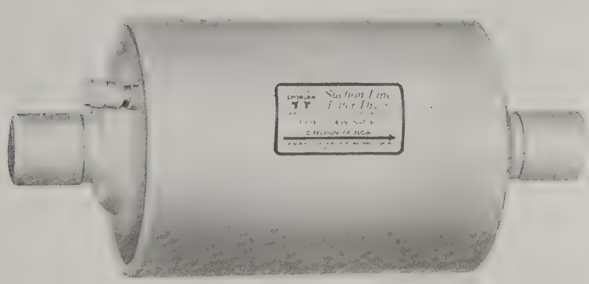


Fig. 11-30. Filter-driers are used to remove any residual moisture from a system, as well as trap any foreign particles circulating with the refrigerant. (Sporlan Valve Co.)

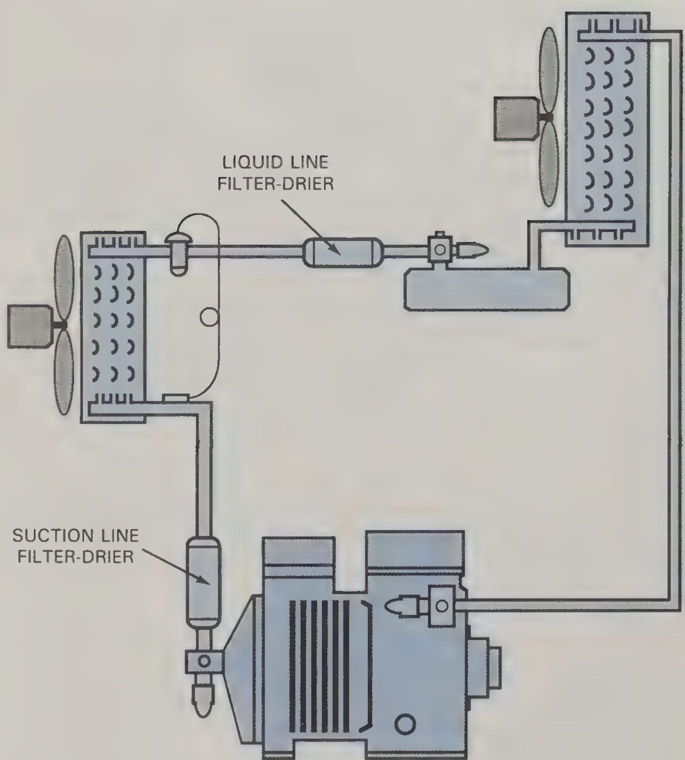


Fig. 11-31. On commercial systems, the filter-drier is usually installed in the liquid line, just after the liquid receiver. For additional protection, technicians sometimes install a second filter-drier, as shown here, between the compressor and evaporator.

MOISTURE PROBLEMS

Water or moisture is always present in refrigeration systems, and must be kept to an absolute minimum. Acceptable limits will vary from one system to another and from one refrigerant to another. Moisture is the primary factor in the formation of acids, sludge, copper plating, and corrosion. The service technician should always be alert to keep the moisture level of the refrigeration system as low as possible.

The three main problems caused by moisture are:

- *Corrosion* that damages metal parts and adds contaminants to the system.
- *Formation of acid* that damages the motor windings. Since the motor windings are exposed to refrigerant, any acid that forms will cause a breakdown of the insulation and result in a motor burnout.
- *Freezing* of moisture in the orifice of the refrigerant control valve or capillary tube can block the flow of refrigerant and stop the operation of the system.

Other sources of problems within the system are dirt, sludge, rust, and foreign matter such as flux, copper or brass chips, and solder. These contaminants can damage piston cylinder walls or compressor bearings, or plug capillary tubes and other refrigerant controls.

PRINCIPLE OF FILTER-DRIER OPERATION

Filter-driers used in refrigeration systems are based on the principle of bringing liquid refrigerant in contact with a substance that will absorb any moisture in the refrigerant. Such a substance is called a drying agent or ***desiccant,*** and is usually capable of removing acid as well as moisture.

If properly sized, the filter-drier will not restrict the flow of refrigerant, even when the desiccant is full of moisture and no longer effective. Desiccants are extremely sensitive to moisture, and must be protected against it at all times until ready for use. The factory seals on a filter-drier should not be removed until just prior to installation. Most filter-driers are direction-sensitive, meaning they must be oriented to the direction of refrigerant flow. Direction-sensitive filter-driers have an arrow printed on the body to indicate the proper direction of flow. See Fig. 11-32.

Desiccants used in filter-driers include activated alumina, silica gel, activated carbon, which ***absorb*** (soak up) moisture, and molecular sieves, which ***adsorb*** (collect substances on their surfaces in a condensed layer) contaminants from the refrigeration system. Desiccants are available in granular, bead, and block forms, Fig. 11-33. Combinations of desiccants can be used in solid cores and have certain advantages over a single desiccant, such as the absorption of a greater variety of contaminants.

Do not attempt to reactivate a used filter-drier. They should be discarded when no longer effective, since they retain trapped oil and acid as well as water.

On the larger commercial systems a replaceable element type of filter-drier is used. This filter-drier is bolted together and replaceable cores are available in vacuum packed metal containers. See Fig. 11-34.

Fig. 11-32. A receiver-drier designed to be attached to the liquid line with flare fittings. Other types are designed for brazing into the line. Note the arrow that indicates proper direction of refrigerant flow through the device. To keep the desiccant at full effectiveness, the seal caps on the fittings should be left in place until just before the filter-drier is installed. (Sporlan Valve Co.)

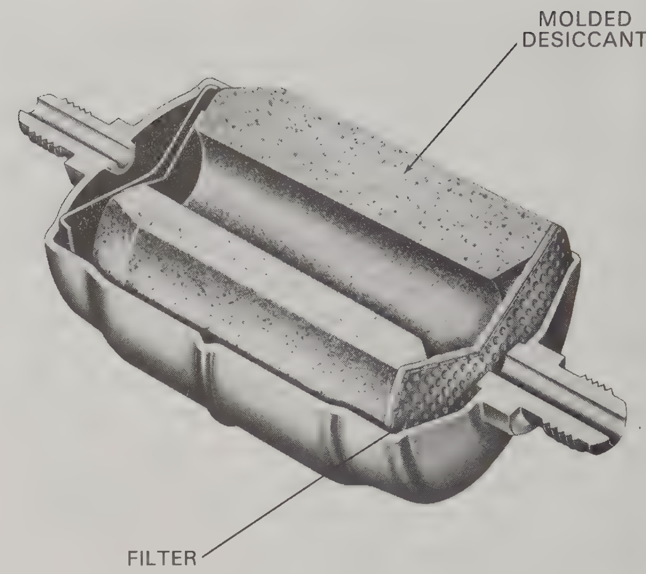
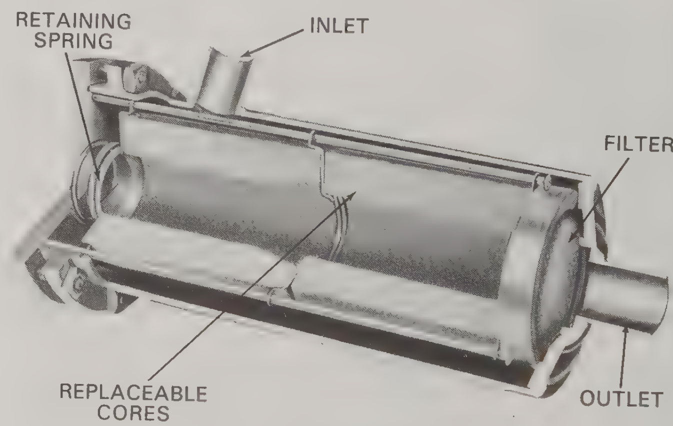


Fig. 11-33. Desiccant granules can be molded into a core for the receiver-drier, as shown in this cutaway view. (Sporlan Valve Co.)



A

B

Fig. 11-34. Replaceable element filter. A–Cutaway view shows the installation of two cores (elements) in the receiver-drier shell. Access is by means of the bolted cover at left. B–Replacement elements are packed in sealed cans that exclude moisture from the air. Typical cores are shown. (Sporlan Valve Co.)

Special acid-removing filter-driers are available for field installation in the suction line. Such filter-driers are often used to clean the system and protect a new compressor following a burnout.

Domestic filter-drier

Domestic systems (refrigerators and freezers) also have a filter-drier, but it is much smaller than those used on commercial systems. The body of the domestic filter-drier is made of copper, because it is brazed into the system at the outlet of the condenser, Fig. 11-35. These filter-driers are normally direction-sensitive, but some small-capacity units are nondirectional.

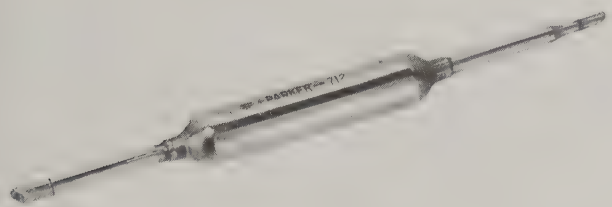


Fig. 11-35. A small filter-drier intended for use in a domestic unit. The copper tubes at each end are brazed into the system at the condenser outlet. Note the directional arrow on the top of the device's body. (Parker-Hannifin)

Domestic systems need a filter-drier to ensure trouble-free operation. Due to the small amount of refrigerant circulating in the system, a single drop of excess moisture will cause a freeze-up. The components in the system are quite small; any foreign material will cause severe problems. When a domestic (hermetic) system is opened for repairs, the filter-drier always should be replaced.

SIGHT GLASS

The ***sight glass***, Fig. 11-36, is a small window placed in the liquid line on commercial systems to provide a view of the flowing liquid. The sight glass serves as a valuable service aid: visible bubbles indicate problems within the system. These problems can be low refrigerant charge, low head pressure, insufficient subcooling, restrictions, or poor piping design. The sight glass is usually located close to the liquid receiver and immediately after the filter-drier, Fig. 11-37.

The sight glass will show clear if the line is full of liquid, and will show bubbles if the system is having problems. An occasional bubble is not unusual or harmful, but excessive bubbles indicate trouble in the system.

While the sight glass will show clear when full of liquid, it also will also be clear when empty. To determine the correct situation, frontseat the liquid receiver service valve and pump down the system down while observing through the sight glass. An empty system will show no change. A full system, however, will appear full, then show bubbles, and then appear empty.

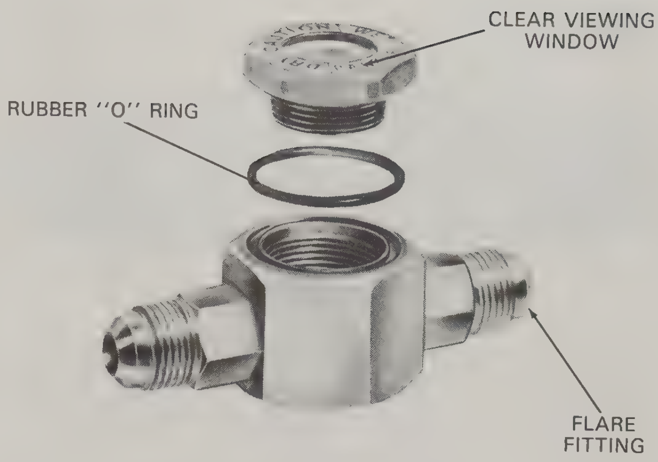


Fig. 11-36. A typical sight glass. The clear window allows the technician to "look inside" the system and diagnose problems by the appearance of the refrigerant. Sight glasses are available with various kinds of fittings to suit different system configurations. (Parker-Hannifin)

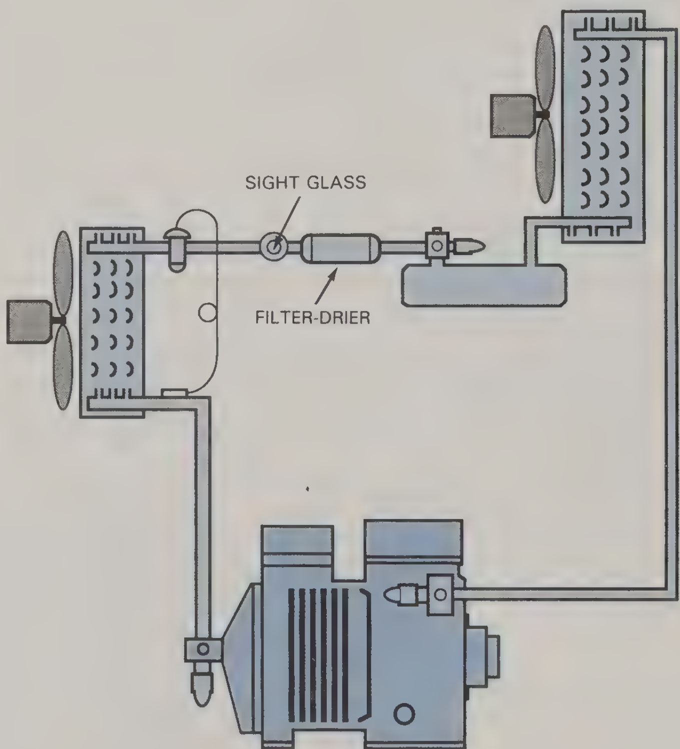


Fig. 11-37. The sight glass is a useful tool for diagnosing system problems. It is normally installed immediately after the filter-drier in the liquid line.

SIGHT GLASS WITH MOISTURE INDICATOR

Most sight glasses have a ***moisture indicator*** centered within the viewing window, Fig. 11-38. The indicator is highly sensitive to moisture, gradually changing color to reflect the moisture content in the refrigerant. The indicator element is completely reversible and will change color as often as the moisture content of the refrigerant varies.

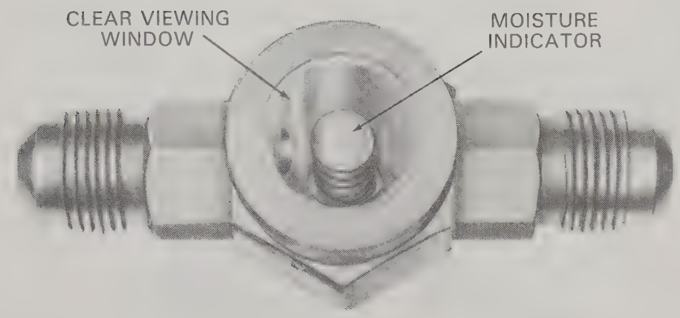


Fig. 11-38. A typical sight glass with a moisture indicator in the center. The indicator will gradually change color to reflect the presence or absence of moisture. (Sporlan Valve Co.)

Some change in color will take place rapidly at the start-up of a new system or after the filter-drier is replaced. It is recommended that the system operate for about 12 hours before you decide (based on the moisture indicator) that another filter-drier change is needed. Drying of the refrigerant should continue until the indicator element changes to the proper color.

All halogenated refrigerants (such as R-12, R-22, or R-502) will accept very small amounts of moisture and still function properly. However, when these levels are exceeded, severe problems will develop. The amount of moisture in a refrigeration system must be kept to an absolute minimum to provide troublefree operation. Therefore, it is important that every precaution be taken to prevent moisture from entering the system during installation or service operations. Any moisture that *does* enter the system should be removed as quickly as possible.

A color reference code is printed around the edge of the sight glass or on the front of the sight glass body, Fig. 11-39. One manufacturer's color code varies from dark green (dry), to light green (caution), to bright yellow (very wet). Another indicator changes color from dark blue (dry), to light blue (caution), to pink (very wet). A plastic or metal cap is provided to keep the glass free of dust, dirt, and grease. This cap should always be replaced. Domestic systems, unlike commercial installations, do not use a sight glass or moisture indicator.

The moisture indicator is chemically engineered for long life, accuracy, and reliability. The same indicator can be used for all common refrigerants. The indicator element will indicate a wet condition before installation, but this is normal and simply reveals ambient humidity. Most sight glasses are installed with flare connections, but sweat types are available.

HEAT EXCHANGER

The term heat exchanger is a general one used to describe any device used to transfer heat from one medium to another. However, in the commercial refrigeration industry, the term ***heat exchanger*** describes a particular component that transfers heat from the warm liquid line to the cold suction line, Fig. 11-40. The heat exchanger performs two tasks:

- It subcools the refrigerant in the liquid line before it reaches the refrigerant control valve, improving system efficiency.
- It superheats vapor inside the suction line with heat removed from the warm liquid line. This prevents liquid refrigerant from reaching the compressor.

The design of the heat exchanger is based upon the principle of mutual benefit. In theory, the liquid line is wrapped around the suction line for several turns before traveling to the refrigerant control valve. Some heat exchangers use the tube-in-a-tube design, which is very efficient. In domestic models, the small capillary tube used for the refrigerant control is soldered to the suction line for almost its entire length.

Heat exchangers are designed to perform this dual function in a system and they should not be added to, or removed from, a system without proper engineering information.

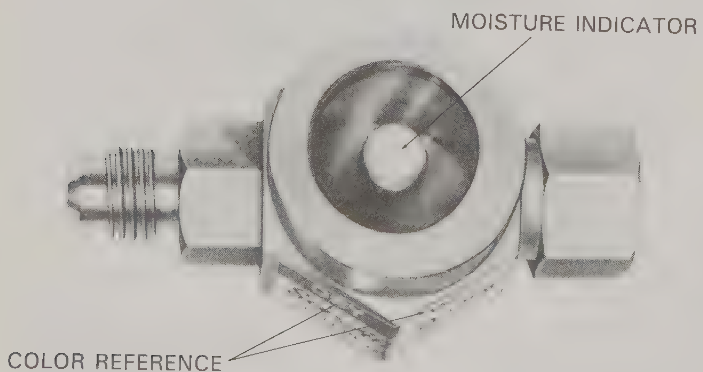


Fig. 11-39. Colors that the moisture indicator uses to show wet or dry conditions are displayed on the sight glass rim or body. In this example, the color reference is on a label attached to the body. Colors for each condition will vary from manufacturer to manufacturer. (Sporlan Valve Co.)

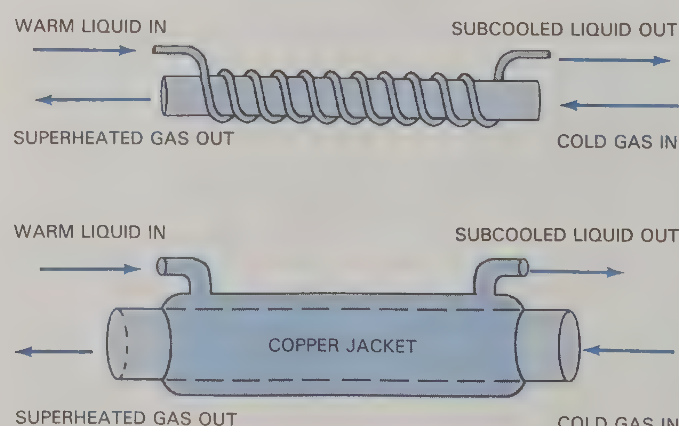


Fig. 11-40. A heat exchanger has a dual role: it subcools liquid refrigerant in one line and superheats refrigerant gas in the other.

SUCTION ACCUMULATOR

The *suction accumulator* is a device used to keep liquid refrigerant from entering the compressor, Fig. 11-41. The accumulator is a cylinder that acts as a trap to collect liquid refrigerant and permits only vapor to exit. Liquid entering the accumulator must boil off inside the device before exiting as a vapor.

Domestic systems locate a small accumulator at the evaporator outlet, with the suction line coming out the top of the accumulator. This prevents liquid from entering the suction line. Liquid entering the bottom of the accumulator will remain inside it until the liquid boils. Only vapor can exit and enter the suction line at the top of the accumulator.

The accumulator is basically an upright cylinder with two openings in the top: the *inlet* and the *outlet,* Fig. 11-42. The suction line is brazed to the inlet opening; any liquid refrigerant entering from that line will fall to the bottom of the cylinder. The outlet opening has a dip tube that goes to the bottom of the cylinder, makes a 180° bend and extends upward toward the top of the cylinder where only vapor can enter the tubing to the compressor suction service valve.

Liquid refrigerant is trapped in the bottom of the accumulator until it evaporates. A small hole (called an ***aspirator hole***) is drilled in the side of the 180° degree bend. This permits small quantities of oil to enter the outlet tube and be drawn back to the compressor. Without this aspirator hole, the accumulator would trap oil and deprive the compressor of proper lubrication. Small amounts of liquid refrigerant may enter the aspirator hole, but will evaporate before reaching the compressor and are, therefore, harmless.

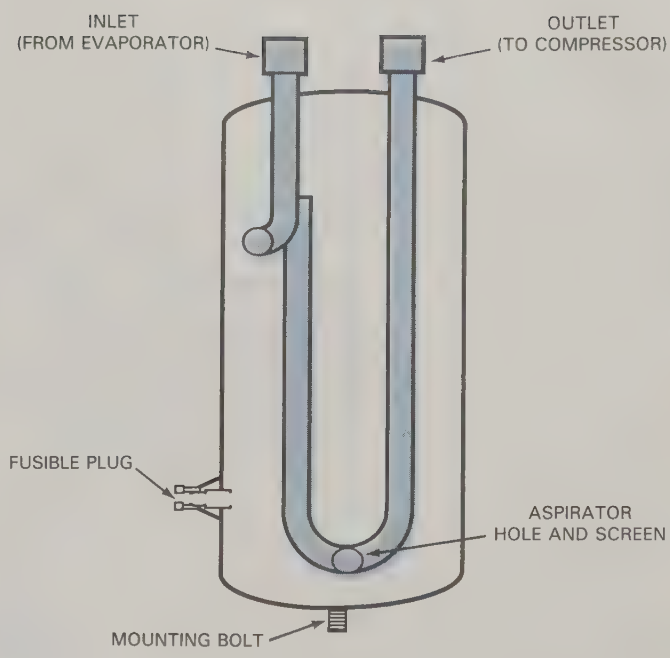


Fig. 11-42. Interior view of a suction accumulator. The 180° bend of the outlet tube permits only vaporized refrigerant to emerge from the accumulator.

SUMMARY

Fig. 11-43 illustrates a refrigeration system that includes all of the components introduced in this chapter. Each component serves a definite purpose. A refrigeration system will seldom have all these "extra" components, but some are found on every system. Many systems require the use of some accessory components to properly control the movement and condition of the refrigerant.

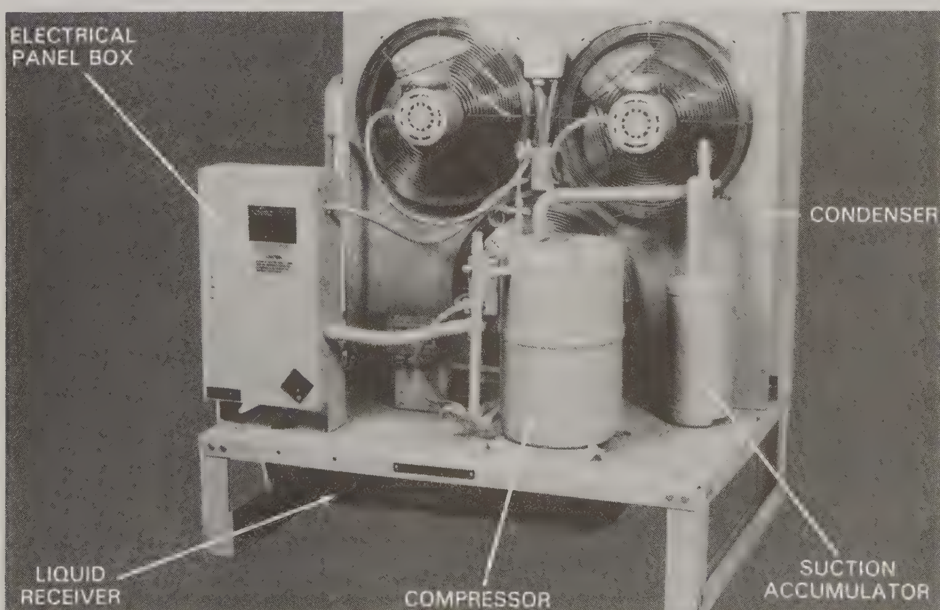


Fig. 11-41. A commercial condensing unit, showing the relationship of the suction accumulator and the compressor. The accumulator keeps liquid refrigerant from reaching the compressor. (Hussmann Corporation)

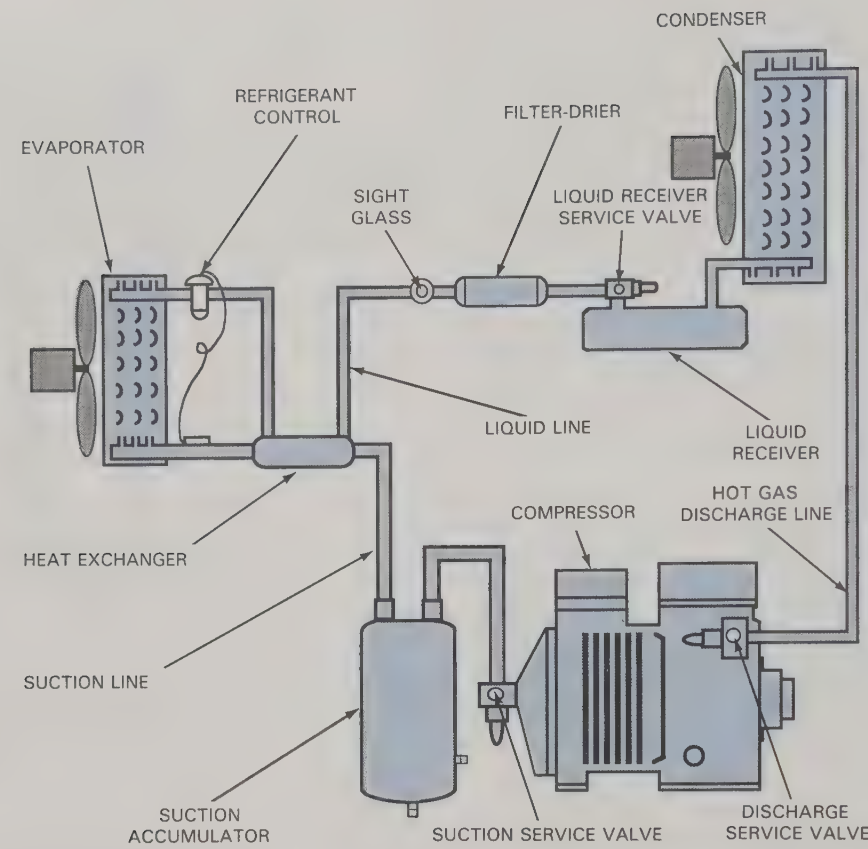


Fig. 11-43. A complete refrigeration system, with all the components discussed in this chapter. A system will seldom have all these components, but every system has at least some of them.

This chapter was devoted to explaining the mechanical operation of accessory components and *why* these components are used on different systems. All systems are designed to control the movement and condition of the refrigerant. Later chapters will explain how the system itself is controlled. Troubleshooting and repair procedures cannot be understood without knowing how and why each component effects the system. Being able to draw the entire system (as shown in Fig. 11-43) from memory will prove a definite "plus" as you study later chapters.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What two copper lines connect the evaporator section with the condensing unit?
2. Where is the condensing unit located on a domestic refrigerator?
3. What is the purpose of the liquid receiver?
4. The liquid receiver should never be more than ________% full when it contains the system's entire refrigerant supply.
5. Name three service valves that are used on commercial systems.
6. When a service valve is backseated, which opening is closed?
7. When a service valve is backseated and then "cracked," which opening is closed?
8. Frontseating the suction service valve will close which opening?
9. What is the name of the fitting used on service valves to install gauges? What sizes and thread types are each end of the fitting?
10. Are hand valves on the gauge manifold normally closed or open?
11. Hand valves on the gauge manifold control access to the ________ hose.
12. At which two valves can you obtain high pressure readings?
13. Name two types of valves installed by technicians on domestic systems.
14. Where is the filter-drier located?
15. What is the purpose of the filter-drier?
16. What does a large number of bubbles in the sight glass indicate?
17. Where is the sight glass installed?
18. What is the purpose of the moisture indicator?
19. A heat exchanger has a two-fold purpose. Describe what it does.
20. Name all fifteen possible system components, in order of refrigerant flow, beginning at the evaporator.

Chapter 12
REFRIGERANTS

After studying this chapter, you will be able to:
- *Recognize and identify different refrigerants.*
- *Exhibit awareness of ozone layer depletion problems.*
- *Describe how to use temperature-pressure charts.*
- *Discuss how to determine superheat at any location in a refrigeration system.*
- *Recognize compression ratio problems.*
- *Explain temperature application levels.*
- *Describe and use proper safety precautions.*

NEW WORDS

azeotropic blend
azeotropic mixture
CFCs
chlorofluorocarbons
compression ratio
cryogenic
dichlorodifluoromethane
enthalpy
freezing
Freon-12
frozen storage
halide refrigerants
halogens
HCFCs
HFCs
hydrochlorofluorocarbons
hydrofluorocarbons
in-line freezing
latent heat value
monochlorodifluoromethane
Montreal Protocol
ozone depletion
reclaim
recover
recycle
recycling units
saturation pressure
standard conditions
subcooling
superheat
toxicity
ultra-low

WHAT ARE REFRIGERANTS?

Refrigerants are the necessary working fluids used in every refrigeration system. To achieve low temperatures, it is necessary to select a refrigerant that has a boiling point lower than the lowest desired temperature. This is required because heat always flows from the warmer to the colder substance.

Factors other than boiling point also must be considered when selecting a refrigerant. These include toxicity, flammability, operating pressures, and Btus absorbed per pound. Some modern refrigerants can be used in a variety of systems; others have more limited applications.

Many refrigerants are presently available and others are being developed. It is not possible for this book to describe all of the available refrigerants. Such detailed information is obtainable from manufacturers, supply houses, or the local library. Instead, this chapter will concentrate on the composition, selection principles, identification, and application of the most common refrigerants. You may at times encounter different refrigerants, but the principles and practices described in this chapter will still apply.

HISTORY OF REFRIGERANTS

Key events in the development of refrigerants and the refrigeration/air conditioning industry are listed below:

In 1834, the first practical compression-cycle refrigeration system was built.

In 1850, the absorption machine was developed. It used water and sulfuric acid as the refrigerant.

In 1873, the ammonia compressor was introduced.

In 1876, the sulfur dioxide compressor was developed and introduced.

By 1890, the demand for smaller domestic and light commercial systems was increasing rapidly.

By 1900, use of the electric motor became widespread.

By 1915, sulfur dioxide systems were common. **Note:** Both sulfur dioxide and ammonia are highly toxic refrigerants. Exposure can produce serious injury or death.

In 1928, research to discover a new refrigerant was begun by General Motors and DuPont Chemical Company. Researchers sought a revolutionary substance that would be nontoxic, nonflammable, odorless, and noncorrosive. These experiments involved combining halogens such as fluorine and chlorine with hydrocarbon compounds.

In 1930, DuPont began manufacturing the first of many new refrigerants using halogen/hydrocarbon compounds. The first compound to be marketed (under the tradename ***Freon-12***) was ***dichlorodifluoromethane.*** It was introduced in 1931.

Freon-12 molecules were extremely stable (did not break down), and had many other valuable qualities. This refrigerant revolutionized the refrigeration and air conditioning industry, and lead to its rapid growth. Many other refrigerants under DuPont's "Freon" tradename quickly followed.

HALIDE REFRIGERANTS

The most widely used refrigerants contain one or more of the chemical substances called ***halogens.*** Halogen substances are fluorine, chlorine, iodine, and bromine. Halogens are combined with a hydrocarbon compound, such as acetylene, methane, or ethane, to produce what are referred to as ***halide refrigerants.***

The manufacturing process for halide refrigerants is complicated, because each mixture is precise and must produce an entirely new substance that has a specific boiling point and acts according to Charles's Law of Gases. The new compound molecule also must be stable (not break down spontaneously). An example of such a compound is the combining of hydrogen with oxygen to form water (H_2O).

The halide refrigerants are classified into three groups, according to their chemical makeup. These are the *chlorofluorocarbons,* the *hydrochlorofluorocarbons,* and the *hydrofluorocarbons.*

CHLOROFLUOROCARBONS

Chlorofluorocarbons are refrigerants that are composed of chlorine, fluorine, and a hydrocarbon (methane). Such refrigerants are classified as ***CFCs.*** Examples are R-11 (trichloromonofluoromethane) and R-12 (dichlorodifluoromethane). The Greek prefixes *mono, di,* and *tri* indicate how many parts of a substance are used in the compound. Mono means 1 part, di means 2 parts, and tri means 3 parts.

The name for R-12, dichlorodifluoromethane, describes the molecular structure of the compound. R-12 contains two parts chlorine "*di*chloro" and two parts fluorine "*di*fluoro", combined with methane. Therefore, the number **2** will appear *twice* in the chemical formula: CCl_2F_2. See Fig. 12-1.

R-11 (often referred to as "carrene" or methylene chloride)) and R-12 were the first halide refrigerants and have become very popular. R-113, R-114, and R-115 are also CFCs, but are not well-known.

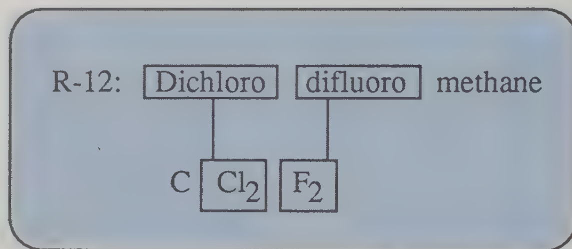


Fig. 12-1. The chemical name and chemical formula of a refrigerant describe its molecular structure. A molecule of R-12 (dichlorodifluoromethane) includes two chlorine atoms and two fluorine atoms combined with a methane molecule.

CFCs and ozone depletion

In recent years, much concern has been raised about CFCs and the effect (***ozone depletion***) that the chlorine they contain has upon the environment. The ozone layer of our atmosphere, about 15 miles up, shields the earth against excess ultraviolet radiation from the sun. Scientists believe that excess ultraviolet radiation reaching the earth will lead to eye damage and increased skin cancer rates. Ozone depletion may also cause climate changes that could disrupt delicate food chains.

Most of the attention has focused on widely used CFCs such as R-11 and R-12, but there is growing concern over other refrigerants, such as R-500 and R-502. The federal Clean Air Act contains regulations on venting of refrigerants to the atmosphere.

Chlorine cannot normally reach the ozone layer. CFCs are very stable chlorine-containing compounds that do not break up in the atmosphere like other, less-stable refrigerants. The CFC molecules act as a "carrier" to lift chlorine atoms to the ozone layer. There, the CFC molecules absorb ultraviolet radiation from the sun and decompose. As the molecules break up, chlorine is released and attacks the protective ozone layer.

CFC-11 and CFC-12 have an ozone depletion level of 1.0 (maximum). All other refrigerants are compared to this level. See Fig. 12-2.

The CFC ozone depletion problem resulted in a meeting of eleven industrialized nations in Montreal, Canada. This group reached an agreement, called the ***Montreal Protocol,*** to substantially reduce production

OZONE DEPLETION LEVELS	
REFRIGERANT COMPOUND	**DEPLETION LEVEL**
CFC-11	1.0
CFC-12	1.0
CFC-113	.8
CFC-502	.307
HCFC-22	.05
HCFC-123	.02
HCFC-124	.02
HCFC-141b	.10
HCFC-142b	.06
HFC-125	.00
HFC-134a	.00
HFC-152a	.00

Fig. 12-2. Ozone depletion levels for various refrigerants. A 1.0 level, as exhibited by CFC-11 and CFC-12, represents the highest level of ozone layer damage. All other depletion-level values are based on 1.0. CFC-502, for example, is only about 1/3 as damaging (.307) as R-12, in terms of ozone depletion. The HFC compounds do no damage to the ozone, and are thus rated at 0.0.

of ozone-depleting CFCs. From 1989 to 1993, all manufacturers have been limited to CFC production at 1986 levels. A further production cut of 20 percent was scheduled for 1993, and another of 30 percent for 1998. By the year 2000, CFCs can no longer be produced.

This scheduled elimination of CFC production has caused refrigerant manufacturers to seek alternatives for CFC refrigerants. The industry must phase out CFCs while introducing alternatives or replacements. Much attention is being focused on conservation, recovery, recycling, and disposal of CFC refrigerants. A number of recovery and recycling systems are now available, and new ones are being developed. See Fig. 12-3.

Refrigerant recovery equipment is used to avoid releasing refrigerant into the atmosphere when making repairs to a refrigeration system. The recovery equipment is essentially a refrigeration system used to remove and store liquid refrigerant in a *refillable* cylinder. After repairs are completed, the stored refrigerant is then recharged into the original system.

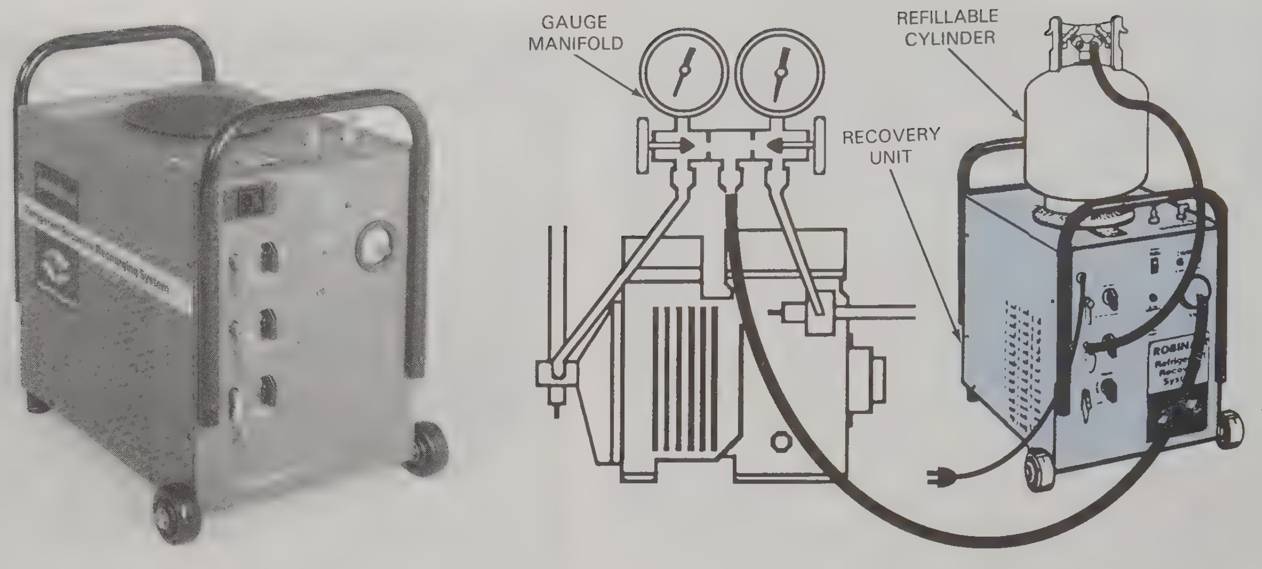
Refrigerant recovery is accomplished by connecting a gauge manifold to the system requiring repair, then connecting the middle (yellow) hose to a small filter-drier on the recovery unit. The hose will serve as a suction line for withdrawing gaseous refrigerant from the system. The recovery unit includes an evaporator, compressor, condenser, oil separator, various safety devices, and a refillable cylinder for liquid storage. See Fig. 12-4. Care must be exercised to avoid overfilling the cylinder.

The special heavy-duty refillable cylinders used in both recovery and recycling units must meet U.S. Department of Transportation regulations. As shown in Fig. 12-5, the cylinders normally have two valves. One valve is marked *liquid,* the other, *vapor.* The liquid valve has a dip tube that reaches to the bottom of the cylinder, making it possible to remove liquid or vapor without turning the cylinder upside down.

Fig. 12-3. Refrigerant recovery and recycling (reclaim) systems are coming into widespread use. This unit is used to recycle refrigerant, cleaning it of such contaminants as moisture, acid, oil, and foreign particles. (Van Steenburgh Engineering Laboratories, Inc.)

Recovered refrigerant can simply be returned to the system from which it was originally withdrawn, but must be cleaned of any contamination before it can be used in *another* system. ***Recycling units*** are used to remove most contaminants and make the refrigerant suitable for reuse. See Fig. 12-6. The units consist basically of a liquid pump and an oversize filter-drier with a replaceable filter element. The pump withdraws the liquid refrigerant from the bottom of the cylinder through the dip tube and liquid valve. The refrigerant then circulates through the filter-drier, and is returned to the cylinder through the vapor valve. It may take four to six hours of circulation (with several filter element changes) to remove all moisture and acid from the refrigerant.

CFCs are becoming scarce and high-priced, making the process of recycling an economically attractive option. Systems using CFCs must be protected against loss of refrigerant and require service procedures that prevent (or minimize) escape of CFCs into the atmo-



A B

Fig. 12-4. Refrigerant recovery. A–Recovery equipment is equipped with wheels for ease of moving to the work site. (Robinair Mfg. Corp.) B–Refrigerant is withdrawn from the refrigeration system as a vapor, then is condensed to a liquid by the recovery equipment. The liquid is stored in a refillable cylinder. The recovery unit will shut off when the cylinder is 85 percent full or when the refrigeration system is empty, if that occurs first.

sphere. Recovery, reclamation, recycling, and/or disposal present new opportunities for technicians.

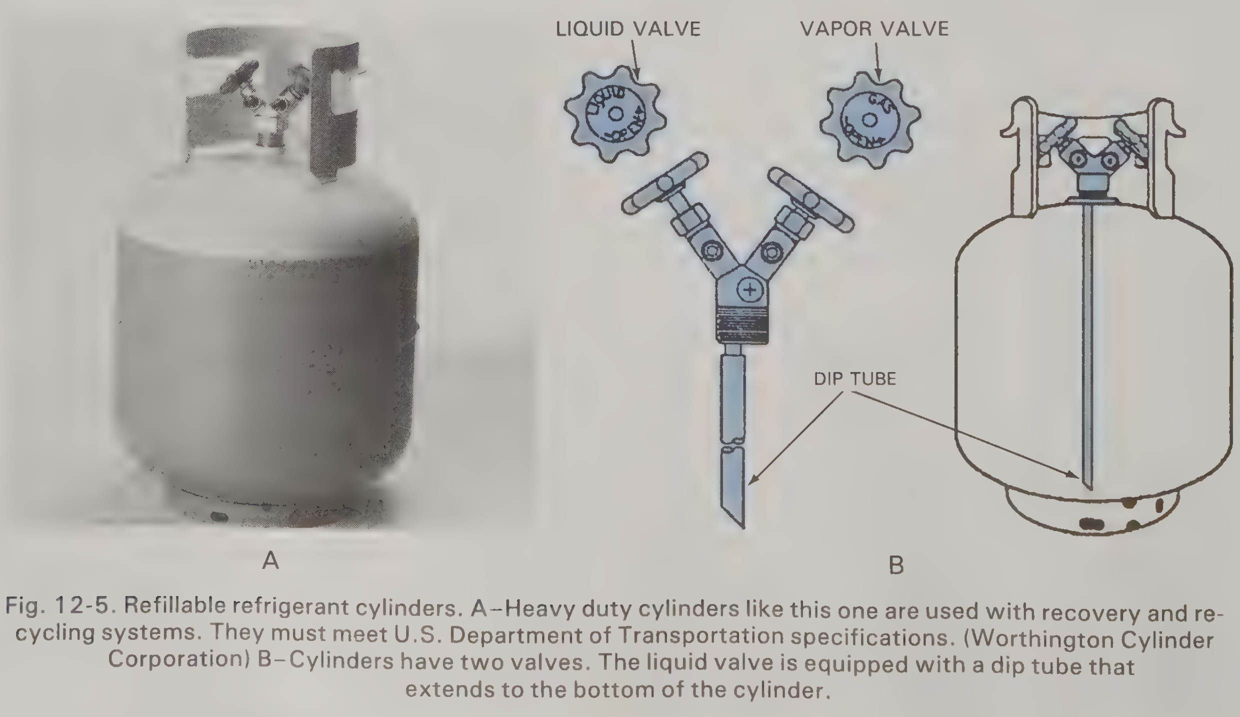
Using new terms correctly

The words ***recover, recycle,*** and ***reclaim*** are new terms with specific meanings. To use these terms correctly, it is important to understand the differences in their meanings.

Recover. This term means to remove refrigerant from a system and store it in a refillable cylinder. Recovered refrigerant is not tested, cleaned, or processed in any way.

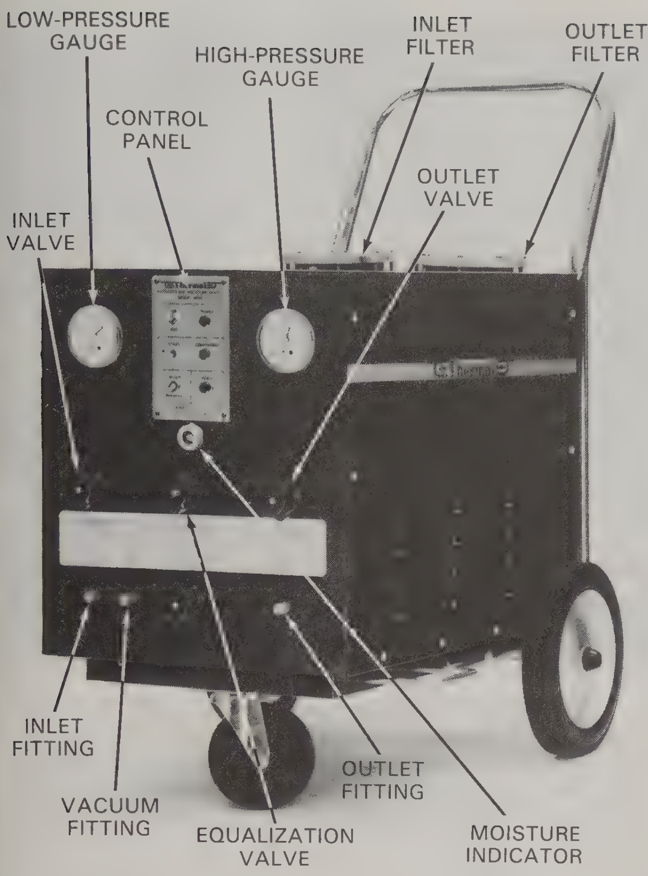
Recycle. This term means to clean recovered refrigerant for reuse. The recycling process involves recirculation of the liquid refrigerant through one or more filter-driers. The filter-driers reduce moisture, acidity, and particulate matter. Recycling units do *not,* however, clean refrigerant to new purity standards. Recycling is usually done at the job site or a local service shop.

Reclaim. This term is used to describe reprocessing of recovered refrigerants to meet new product specifications (as described in ARI Standard 700-88). Chemical analysis is needed to ensure that specifications have



A B

Fig. 12-5. Refillable refrigerant cylinders. A–Heavy duty cylinders like this one are used with recovery and recycling systems. They must meet U.S. Department of Transportation specifications. (Worthington Cylinder Corporation) B–Cylinders have two valves. The liquid valve is equipped with a dip tube that extends to the bottom of the cylinder.



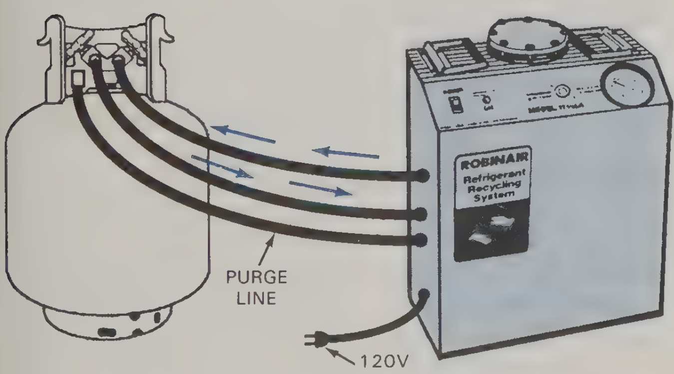


Fig. 12-6. Refrigerant recycling. A–Recycling unit used to remove contaminants from refrigerant to allow reuse. (Thermal Engineering) B–A pump draws liquid refrigerant from the bottom of the cylinder and circulates it through a filter-drier that has a replaceable filter element. After all moisture and contaminants have been removed, the refrigerant can be used to charge a refrigeration system. (Robinair Mfg. Corp.)

been met. The term *reclaim* is usually used to refer to the use of processes available only at a manufacturing or reprocessing facility.

HYDROCHLOROFLUOROCARBONS

Hydrochlorofluorocarbons, known as ***HCFCs***, contain hydrogen atoms that cause the compound to be less stable in the atmosphere than CFCs. HCFCs are considered less harmful to the ozone layer than CFCs, because they break up rather quickly when released to the atmosphere. Only a small percentage of the chlorine they contain is able to reach the ozone layer. The most widely used HCFC is ***monochlorodifluoromethane,*** designated as R-22. Other examples of HCFCs are R-123, R-124, R-141b, and R-142b. These refrigerants are not included in the Montreal Protocol because their ozone depletion level is very low.

HYDROFLUOROCARBONS

Hydrofluorocarbons, or ***HFCs,*** contain no chlorine atoms. These refrigerants are considered environmentally safe, with an ozone depletion level of 0 (no chlorine). Examples are R-125 and R-152a.

ALTERNATIVE REFRIGERANTS

Recent discoveries have produced new alternative refrigerants for CFC-11 and CFC-12. These new refrigerants are not *replacements* for R-11 and R-12, since they are not compatible with present equipment or refrigeration oils. They also have less capacity in Btu/lb. of liquid circulated.

These alternative refrigerants cannot be used with regular refrigeration oils, which are refined mineral oils. New oils were developed for use with the new refrigerants. The first synthetic oil was made of polyalkaline glycol (PAG), and could not be used in existing equipment. The second generation of synthetic oils (See Chapter 18) is more compatible with existing systems, so conversion (retrofitting) is possible by using critical step-by-step flushing procedures.

Refrigerant HFC-134a is the new alternative for CFC-12, and HCFC-123 is the new alternative for CFC-11. Other alternative refrigerants are being developed, with considerable effort being devoted to finding ozone-safe "drop-in replacements" for existing CFCs.

REFRIGERANT NUMBERING SYSTEM

DuPont's numbering system for refrigerants came into general use in 1956. By that time, several other chemical companies were manufacturing halogenated refrigerants (those containing chlorine or fluorine). Each separate refrigerant chemical (such as dichlorodifluoromethane) was given a number and each company produced these refrigerants under its own brand name. For example, DuPont's trademark for dichlorodifluoromethane was **Freon-12,** while Allied Chemicals used **Genetron-12,** and Virginia Chemicals used **Isotron-12.**

The American Society of Refrigerating and Air Conditioning Engineers (ASHRAE) has standardized identification of all refrigerants. This system uses the DuPont numbering system, but precedes each number by the letter **R** (for refrigerant), regardless of manufacturer.

This method includes the old toxic refrigerants, such as sulfur dioxide (R-764) and ammonia (R-717). All manufacturers now follow this identification procedure. See Fig. 12-7.

In response to concern about ozone depletion problems, recent industry usage has been to drop the **R** and replace it with letters describing the chemical composition of the refrigerant: CFC-12, HCFC-22, and HFC-134a.

REFRIGERANT CYLINDER COLOR CODES

Most refrigerant cylinders are color-coded for ease of identification and to help prevent accidental mixing of refrigerants. See Fig. 12-8. Color codes used for some of the most common refrigerants are:

R-11 Orange
R-12 White
R-22 Green
R-114 Dark blue
R-500 Yellow

Since color-coding is not a requirement for all manufacturers, make it a practice to always check the R-number in addition to the cylinder color code.

In addition to the R-number and color code, it is sometimes necessary to know the name and/or chemical formula. All condensing units have a data plate containing information specifying the refrigerant used by number or name, and the amount in pounds and ounces. Examples:

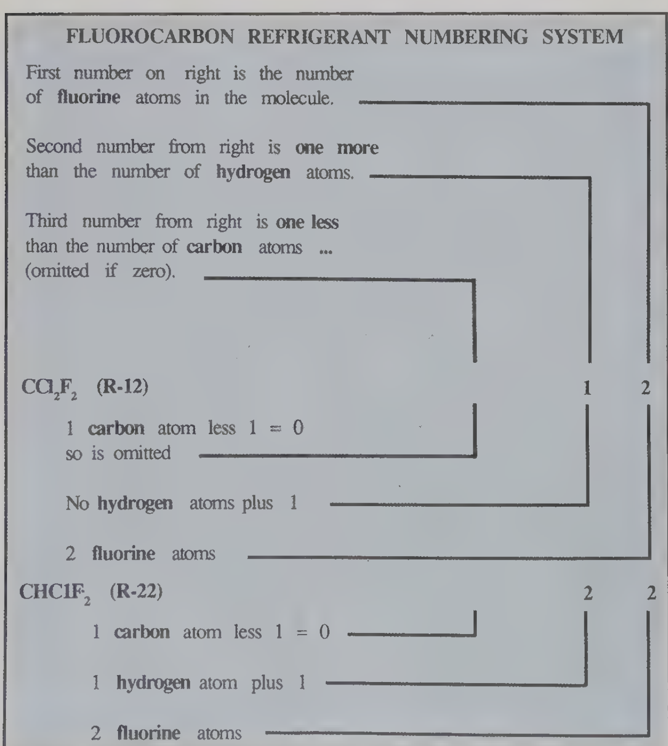


Fig. 12-7. The numbering system developed by DuPont has been adopted by all refrigerant manufacturers. This illustration shows how the designations R-12 and R-22 were developed.

Fig. 12-8. Refrigerants are available in several different sizes of drums and cylinders. To prevent accidental mixing of refrigerants, each has been assigned a specific color (white, in the case of R-12). The trade name and refrigerant number are prominently displayed on the label of each container. (Allied/Signal)

Refrigerant 12: 28 lbs
Dichlorodifluoromethane: 28 lbs.

Service technicians must know these names and formulas because using the wrong refrigerant, or mixing refrigerants, will create severe problems in the system.

AZEOTROPIC MIXTURES

Liquid mixtures of two or more refrigerants that combine to form a new single refrigerant are called ***azeotropic mixtures.*** Such a mixture must maintain a constant boiling point and act as a single refrigerant strictly conforming to Charles's Law of Gases. These are special refrigerants and the manufacturing process is complicated. The service technician should never attempt to make refrigerant mixtures. If the mixing procedure is not precise, the result will not be azeotropic and will perform according to Dalton's Law of Gases. The two most common azeotropic refrigerants are:

R-500: 73.8% R-12 and 26.2% R-152a
Formula: CCl_2F_2/CH_3CHF_2 (R-12 + 152a)
Color code: Yellow
Boiling point: -28°F° (-33.3°C) at atmospheric pressure

R-502: 48.8% R-22 and 51.2% R-115
Formula: $CHClF_2/CClF_2CF_3$ (R-22 + R-115)
Color code: Orchid
Boiling point: -50.1°F (-45.6°C) at atmospheric pressure

R-500 is an older refrigerant that was invented to improve the Btu/lb. capacity of R-12. It provides about 20 percent greater refrigerating capacity for the same size compressor. Its latent heat value at 5°F (-15°C) evaporating temperature is 82.45 Btu/lb., whereas R-12 is 68.2 Btu/lb. This means that R-500 will absorb more heat per pound of refrigerant circulated than R-12. R-500 is used in some older heat pump applications, domestic dehumidifiers, and some commercial or industrial applications where higher capacity is needed.

Servicing refrigeration systems using R-500 is much like servicing units containing R-12. R-500 will readily absorb moisture, which causes damage to the refrigeration system. It is vital that moisture be kept out of refrigeration systems by careful dehydration and installation of driers.

R-502 was discovered in 1961. It is an excellent refrigerant for low temperature applications where temperatures from 0°F to -60°F (-18°C to -51°C) are desired. R-502 has very good capacity (Btu/lb.), and a lower condensing pressure than R-22. The lower condensing pressure increases the life expectancy of the compressor. Better lubrication is possible and liquid injection to cool the compressor is usually eliminated.

R-502 will hold 1-1/2 times more moisture than R-12 before that moisture becomes a problem. The higher suction pressure at low temperatures improves oil return to the compressor, but oil separators are frequently used to assure proper oil levels inside the compressor. All low-temperature systems experience some difficulty with oil return. Refrigerant R-502 has good solubility in oil, and good piping practice assures proper velocity for sweeping oil back to the compressor.

An azeotropic mixture is the combining of *two* refrigerants. When three or more refrigerants are combined, it is called an ***azeotropic blend.***

INORGANIC REFRIGERANTS

The 700 series of numbers indicate inorganic refrigerants such as ammonia or carbon dioxide. The two numbers on the right represent molecular weight of the substance. The molecular weight of ammonia is 17, so the refrigerant number is R-717. The molecular weight of carbon dioxide is 44, so the number is R-744.

SELECTING A REFRIGERANT

The halide (halogenated) family of refrigerants are the major factor responsible for the tremendous growth of the refrigeration and air conditioning industry. The properties of these refrigerants have permitted their use under conditions where more flammable or toxic materials would be hazardous. In many cases, one refrigerant may be used in a number of different applications.

The choice of which refrigerant to use for a particular application depends upon several factors. A low boiling point is not the only feature of a good refrigerant. Other important qualities include ***toxicity*** (safety), flammability, latent heat value, suction pressure, condensing pressure, vapor density, compatibility with oil, corrosiveness, and cost.

The ***latent heat value*** (the number of Btus absorbed for each pound of liquid evaporated) is very important. The latent heat value (Btu/lb.) is different for each refrigerant. If the latent heat value for a refrigerant is fairly high, less refrigerant is required and system components can be smaller and less expensive. The latent heat of the refrigerant should be as high as possible, but other factors must also be considered.

Selection of the best refrigerant for a particular system is often a compromise. For example, the pressure in the evaporator must be as high as possible for the boiling temperature desired. A high suction pressure will result in a high-density gas that will sweep oil back to the compressor. A refrigerant having low pressure (or a vacuum) in the evaporator would be a thin gas, and oil return could be a problem.

Where the evaporator pressure should be as high as possible, the condensing pressure should be as *low* as possible. A low condensing pressure will reduce the size of the condensing unit and decrease the load on the compressor. A high condensing pressure will require a high-capacity compressor and may require additional cooling for the compressor.

When selecting a refrigerant, the design engineer tries to achieve high capacity (Btu/lb.) accompanied by low cost and low energy requirements. System components are expensive to purchase and costly to operate. Therefore, the best choice is a refrigerant that has high capacity and low power requirements.

STANDARD CONDITIONS

Because each of the halogen refrigerants is different, it is important to select the best one for each application. Many factors must be considered in the selection process, but the first step is to compare them under standard conditions. ***Standard conditions*** have been established as 5°F (15°C) evaporating temperature and 86°F (30°C) condensing temperature.

See Fig. 12-9 for comparisons under standard conditions of several common refrigerants. Using standard conditions to compare refrigerants provides a quick method of eliminating those that are unsuitable. Final selection is made at actual system operating temperatures. Refrigerant pressure-temperature tables provide this information.

SATURATION POINT

Highly accurate saturation tables and charts have been prepared to help technicians determine which refrigerant is best for each application. At any given temperature, these tables will reveal the correct ***saturation pressure*** (boiling point), the volume occupied by the

THERMODYNAMIC PROPERTIES	R-11	R-12	R-13	R-22	R-113	R-114	R-500	R-502	R-503
Properties at 1 Atmosphere:									
Freezing point, °F.	-168	-252	-294	-256	-31	-137	-254		
Boiling point, ° F.	74.8	-21.6	-114.6	-41.4	117.6	38.4	-28.3	-50.1	-127.6
Condensation at 86° F:									
Specific Heat of Liquid, Btu/lb/cu ft.	.209	.235	.247	.335	.218	.246	.290	.305	.290
Compressor Discharge Temperature, °F.	111	101	-1	128	86	86	105	99	14
Compressor Suction Temperature, °F.	5	5	-100	5	10	20	5	5	-100
Compression Ratio.	6.24	4.08	4.74	4.06	8.02	5.42	4.12	3.75	4.58
Refrigerant Circulated per ton(lb/min)	2.96	4.00	4.30	2.89	3.73	4.64	3.30	4.38	3.72
Horsepower per ton	0.935	1.002	1.12	1.011	0.973	1.045	1.01	1.079	1.15
Coefficient of Performance	5.04	4.70	4.20	4.66	4.84	4.64	4.65	4.37	4.23
Evaporation at 5° F:									
Specific Volume, cu ft/lb (suction gas)	12.27	1.46	1.55	1.25	27.38	4.34	1.50	0.82	1.32
Net Refrigerating effect, Btu/lb	66.8	50.0	46.3	70.0	53.7	44.7	60.6	44.9	55.4
Latent Heat of Vaporization, Btu/lb	83.5	68.2	52.1	93.2	70.6	61.1	82.5	68.9	72.1

Fig. 12-9. Standard conditions–specific evaporating and condensing temperatures–are useful when comparing refrigerants. This table presents nine different refrigerants side-by-side. (LaRoche Chemicals)

saturated vapor (in cubic feet per pound), the density of the saturated liquid (in pounds per cubic foot), and the ***enthalpy*** (heat content) of both vapor and liquid (in Btu/lb.). See Figs. 12-10 through 12-13.

Remember that "saturation" means *boiling point* or *condensing point*. At saturation, a refrigerant can exist as a liquid, a mixture, or all vapor, at the same pressure and temperature. When a refrigerant is at the saturation point, the temperature/pressure relationship is predictable, Fig. 12-14.

Saturation tables do not reveal ***superheat*** or ***subcooling***. A vapor can be superheated without affecting pressure. Likewise, a liquid can be subcooled without affecting pressure. A pressure reading will reveal saturation temperature, but *actual* temperature may be different, Fig. 12-15. The tables automatically assume the refrigerant is saturated. However, actual temperature may be higher or lower (if the refrigerant is superheated or subcooled).

Saturation tables are very useful for comparing refrigerants under various operating conditions. Engineers use these tables to select a refrigerant for a particular system. Service technicians use the temperature-pressure section of the tables to check for proper operation, diagnose system problems, and line sizing.

Each of these tables is based on a single, pure gas that will behave according to Charles's Law. If another gas or group of gases (such as atmospheric air) is permitted

R-12 Properties of Liquid and Saturated Vapor

°F	PRESSURE psia	PRESSURE psig	VOLUME VAPOR cu. ft./lb.	DENSITY LIQUID lb./cu. ft.	HEAT CONTENT BTU/LB. liquid	HEAT CONTENT BTU/LB. vapor
- 100	1.42	27.01*	22.16	100.15	-12.47	66.20
- 75	3.38	23.02*	9.92	97.93	- 7.31	69.00
- 50	7.11	15.43*	4.97	95.62	- 2.10	71.80
- 25	13.55	2.32*	2.73	93.20	3.17	74.56
- 15	17.14	2.45	2.19	92.20	5.30	75.65
- 10	19.18	4.49	1.97	91.70	6.37	76.20
- 5	21.42	6.73	1.78	91.18	7.44	76.73
0	23.85	9.15	1.61	90.66	8.52	77.27
5**	26.48	11.79	1.46	90.14	9.60	77.80
10	29.34	14.64	1.32	89.61	10.68	78.34
25	39.31	24.61	1.00	87.98	13.96	79.90
50	61.39	46.70	.66	85.14	19.50	82.43
75	91.68	76.99	.44	82.09	25.20	84.82
86**	108.04	93.34	.38	80.67	27.77	85.82
100	131.86	117.16	.31	78.79	31.10	87.63
125	183.76	169.06	.22	75.15	37.28	88.97
150	249.31	234.61	.16	71.04	43.85	90.53
175	330.64	315.94	.11	66.20	51.03	91.48
200	430.09	415.39	.08	60.03	59.20	91.28

* Indicates inches of mercury (vacuum)

**Indicates "Standard Conditions." (5°F evaporating temperature and 86°F condensing temperature)

Fig. 12-10. Saturation table for Refrigerant R-12.

R-22 Properties of Liquid and Saturated Vapor						
	PRESSURE		VOLUME VAPOR	DENSITY LIQUID	HEAT CONTENT BTU/LB.	
°F	psia	psig	cu. ft./lb.	lb./cu. ft.	liquid	vapor
- 150	.27	29.37*	141.23	98.34	-25.97	87.52
- 125	.89	28.12*	46.69	96.04	-20.33	90.43
- 100	2.40	25.04*	18.43	93.77	-14.56	93.37
- 75	5.61	18.50*	8.36	91.43	- 8.64	96.29
- 50	11.67	6.15*	4.22	89.00	- 2.51	99.14
- 25	22.09	7.39	2.33	86.78	3.83	101.88
- 15	27.87	13.17	1.87	85.43	6.44	102.93
- 10	31.16	16.47	1.68	84.90	7.75	103.46
5	34.75	20.06	1.52	84.37	9.08	103.97
0	38.66	23.96	1.37	83.83	10.41	104.47
5**	42.89	28.19	1.24	83.28	11.75	104.96
10	47.46	32.77	1.13	82.72	13.10	105.44
25	63.45	48.75	.86	81.02	17.22	106.83
50	98.73	84.03	.56	78.03	24.28	108.95
75	146.91	132.22	.37	74.80	31.61	110.74
86**	172.87	158.17	.32	73.28	34.93	111.40
100	210.60	195.91	.26	71.24	39.67	112.11
125	292.60	277.92	.18	67.20	47.37	112.88
150	396.10	381.50	.12	62.40	56.14	112.73

* Indicates inches of mercury (vacuum)

**Indicates "Standard Conditions." (5°F evaporating temperature and 86°F condensing temperature)

Fig. 12-11. Saturation table for Refrigerant R-22.

R-134a Properties of Liquid and Saturated Vapor

°F	PRESSURE psia	PRESSURE psig	VOLUME VAPOR cu. ft./lb.	DENSITY LIQUID lb./cu. ft.	HEAT CONTENT BTU/LB. liquid	HEAT CONTENT BTU/LB. vapor
- 50	5.6	15.43*	7.55	89.48	-2.779	94.31
- 40	7.5	14.2*	5.72	88.49	00.00	95.82
- 30	9.9	9.56*	4.39	87.49	2.83	97.32
- 20	12.9	3.80*	3.41	86.47	5.71	98.81
- 15	14.7	0.00	3.02	85.96	7.17	99.55
- 10	16.7	1.95	2.69	85.44	8.64	100.28
- 5	18.8	4.18	2.39	84.91	10.13	101.01
0	21.2	6.55	2.14	84.38	11.63	101.74
5**	23.8	8.96	1.92	83.85	13.14	102.47
10	26.7	12.00	1.72	83.31	14.66	103.19
15	29.8	15.13	1.55	82.76	16.19	103.90
20	33.1	18.74	1.40	82.21	17.74	104.61
25	36.8	21.82	1.26	81.65	19.30	105.31
50	60.1	45.62	0.78	78.75	27.27	108.73
75	93.3	78.42	0.50	75.63	35.57	111.95
86**	111.7	96.60	0.42	74.17	39.33	113.28
100	138.8	124.45	0.33	72.22	44.23	114.88
125	199.2	185.26	0.22	68.38	53.33	117.41
150	277.5	262.80	0.15	63.90	63.06	119.30

* Indicates inches of mercury (vacuum)

**Indicates "Standard Conditions." (5°F evaporating temperature and 86°F condensing temperature)

Fig. 12-12. Saturation table for Refrigerant R-134a.

R-502 Properties of Liquid and Saturated Vapor
(Azeotrope of R-22 and R-115)

	PRESSURE		VOLUME VAPOR	DENSITY LIQUID	HEAT CONTENT BTU/LB.	
°F	psia	psig	cu. ft./lb.	lb./cu. ft.	liquid	vapor
- 100	3.26	23.28*	10.46	97.86	-12.55	65.89
- 75	7.28	15.09*	4.96	95.24	- 7.59	68.92
- 50	14.60	.19*	2.59	92.51	- 2.25	71.93
- 25	26.82	12.13	1.47	89.68	3.50	74.87
- 15	33.49	18.80	1.19	88.50	5.91	76.02
- 10	37.26	22.56	1.07	87.90	7.13	76.58
- 5	41.35	26.66	.97	87.29	8.38	77.36
0	45.78	31.08	.88	86.68	9.63	77.69
5**	50.55	35.86	.80	86.06	10.91	78.24
10	55.70	41.00	.73	85.43	12.19	78.78
15	61.23	46.53	.67	84.80	13.49	79.31
25	73.50	58.81	.67	83.50	16.14	80.35
50	112.12	97.42	.56	80.06	22.98	82.80
75	163.82	149.13	.37	76.22	30.12	84.96
86**	191.28	176.59	.22	74.45	33.36	85.79
100	230.89	216.19	.17	71.97	37.56	86.71
125	316.60	301.36	.12	66.84	45.36	87.84
150	423.06	408.35	.08	60.09	53.85	87.76
175	559.41	544.72	.05	47.55	65.69	83.37

* Indicates inches of mercury (vacuum)

**Indicates "Standard Conditions." (5°F evaporating temperature and 86°F condensing temperature)

Fig. 12-13. Saturation table for Refrigerant R-502.

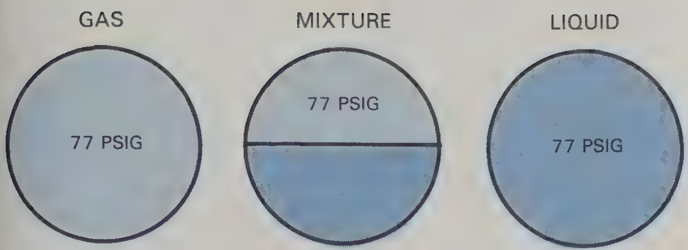


Fig. 12-14. A refrigerant can exist as a gas, a liquid, or a mixture–all at the same pressure–at the saturation point. Saturation temperature in this case is 75 °F.

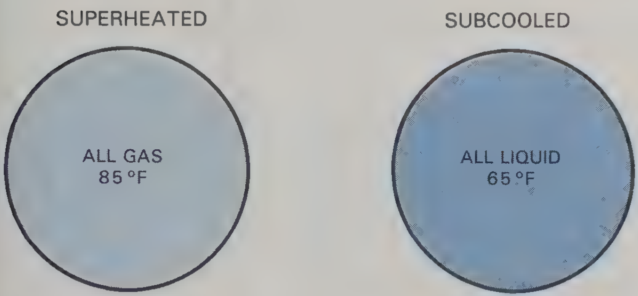


Fig. 12-15. In this example, refrigerant R-12 saturation pressure is 77 psig; saturation temperature 75 °F. In a superheated condition, actual temperature might be 10 degrees above saturation temperature (85 °F). In a subcooled condition, actual temperature might be 10 degrees below saturation temperature (65 °F). In both cases, however, the pressure would still be 77 psig.

to enter the system, then Dalton's Law takes effect, making the table useless. This condition is recognized when the system pressures exceed the saturation tables for a given temperature.

Using temperature-pressure tables

Saturation tables contain the necessary information to predict and control the behavior of each refrigerant. Service technicians are primarily interested in the temperature-pressure relationship, which differs for each refrigerant. Gauges are used to obtain refrigerant *pressure,* and the table is used to convert this pressure to refrigerant *temperature.*

The pressure can be raised or lowered (according to the chart) to achieve the desired refrigerant temperature. All refrigeration systems are designed to control certain temperatures. Other temperatures are regulated through controlling the refrigerant temperature. For example, the temperature of the evaporating refrigerant inside the evaporator is controlled by raising or lowering the low-side pressure. Heat always travels from hot to cold, and the evaporating refrigerant is always the coldest.

There is no universal, all-purpose refrigerant, since each refrigerant responds differently to each change in temperature. Knowing exactly how each refrigerant will behave at a particular temperature makes it easy to locate and correct system problems.

Two pairs of statements will help you remember the relationship of pressure and temperature in a refrigeration system:

Temperature can be controlled by controlling pressure.
Pressure can be controlled by controlling temperature.
Pressure is predictable by knowing temperature.
Temperature is predictable by knowing pressure.

Service and installation technicians are primarily interested in the temperature-pressure relationship, but the tables are also used to help select the best refrigerant for a system, to size suction and liquid lines, and to size such system components as the evaporator, condenser, refrigerant control, and compressor. Proper sizing and selection of these components is very important to efficient operation of the system.

SUPERHEAT AND SUBCOOLING

A superheated gas is one that has a temperature *above* the saturation point. Heat was added *after* the refrigerant changed state from liquid to gas. The temperature of superheated gas will not correspond to the pressure readings on the saturation table. When checking system pressures, the pressure reading shown on the gauge manifold will always be *saturation* pressure. If the refrigerant is superheated, the actual temperature of the gas will be above saturation temperature.

Subcooling is the term used to describe a liquid with a temperature that is *below* the saturation point. Heat was removed *after* the refrigerant changed state from gas to liquid. The temperature of a subcooled liquid will not correspond to saturation pressure.

Superheat and subcooling are important because they are *required* at certain points in the refrigeration system. For example, refrigerant gas inside the suction line is superheated; refrigerant gas entering the condenser is *highly* superheated. Liquid leaving the condenser is subcooled; so is liquid entering the expansion valve. The amount of superheat and subcooling within a system must be controlled, Fig. 12-16.

You can easily determine the amount of superheat or subcooling at any point in the system by using the gauge manifold and a thermometer. Follow this procedure:

1. Obtain a pressure reading with the gauge manifold.
2. Convert the pressure reading to the refrigerant saturation temperature.
3. Using a thermometer, obtain an accurate temperature reading of the copper tubing at the test site.
4. Find the difference in temperature readings (above or below saturation table). This will give you the amount of superheat or subcooling.

COMPRESSION RATIO

Compression ratios are very important when selecting a refrigerant. The ***compression ratio*** is obtained by dividing the absolute suction pressure (psia) into the

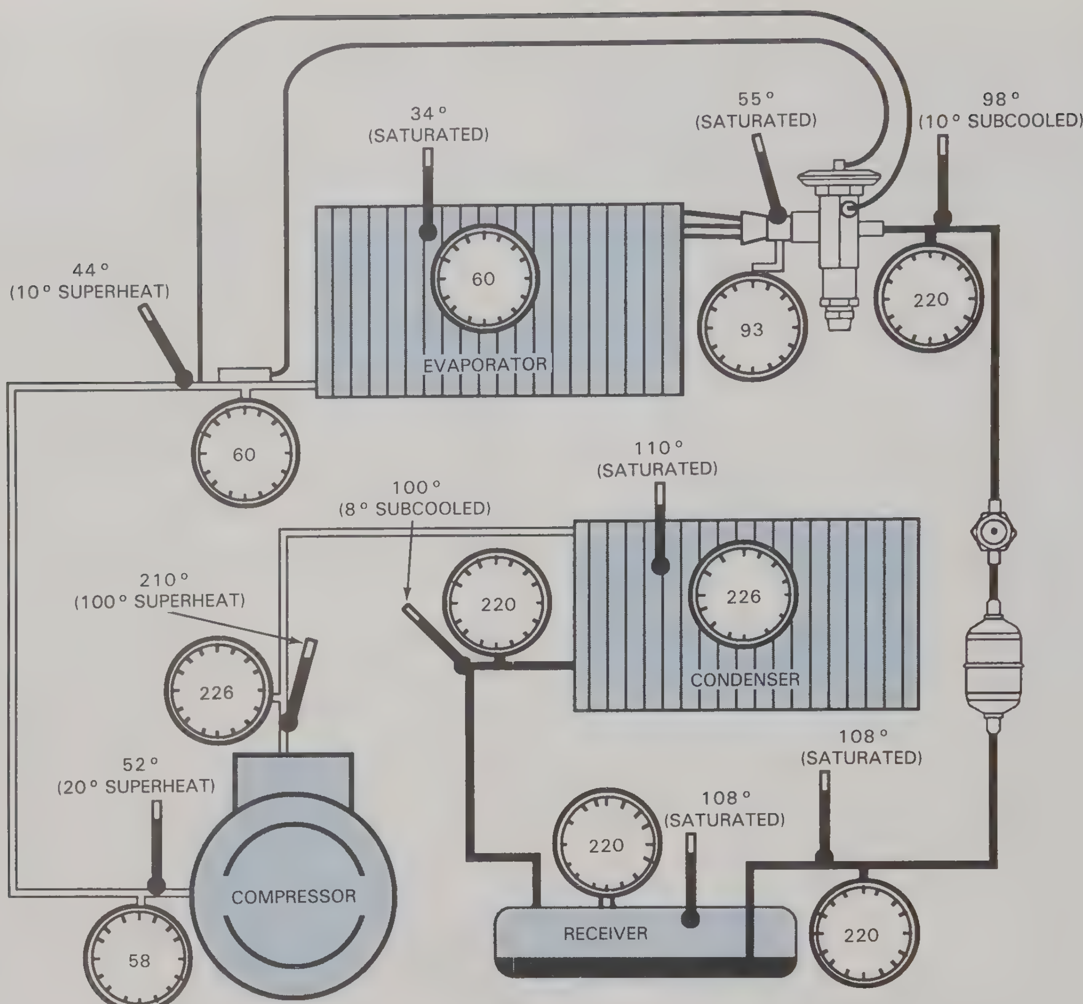


Fig. 12-16. Superheat and subcooling in a typical air conditioning system charged with R-22. The gauges indicate pressure readings in psig at different points in the system.

absolute condensing pressure (psia). A compression ratio of less than 10:1 makes it possible to use a low-capacity (single-stage) compressor; a compression ratio of more than 10:1 usually requires a high-capacity (two-stage) compressor. See Fig. 12-17.

For example, a residential air conditioner using R-22 on a hot summer day (90°F) would have a head pressure of about 260 psig and a suction pressure of about 60 psig. These gauge readings must be converted to absolute by adding 15 psi for atmospheric pressure.

260 + 15 = 275 psia (absolute head pressure)
60 + 15 = 75 psia (absolute suction pressure)
275 ÷ 75 = 3.7 (approximately a 4:1 compression ratio)

Another example would be using R-22 on a low-temperature system, such as a commercial freezer. Here again, on a hot summer day the head pressure would be about 260 psig, but suction pressure would be about 0 psig.

260 + 15 = 275 psia (absolute head pressure)
0 + 15 = 15 psia (absolute suction pressure)
275 ÷ 15 = 18.3 (18:1 compression ratio)

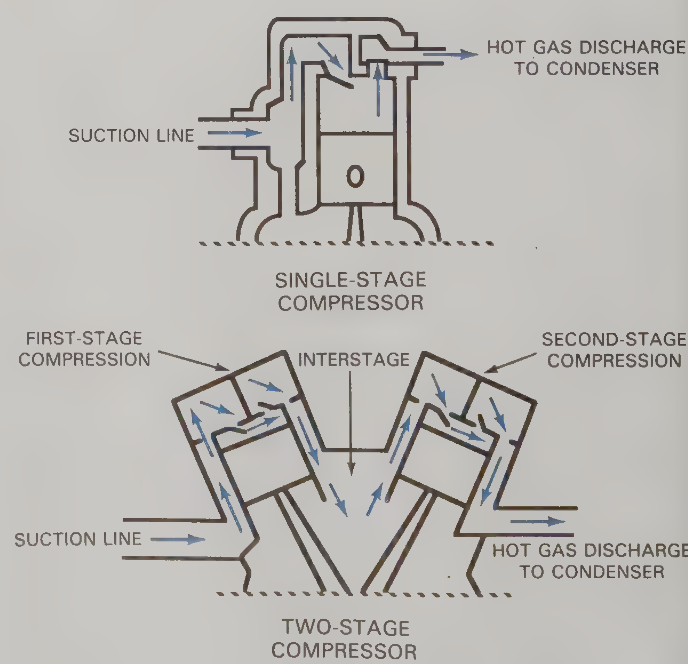


Fig. 12-17. A single-stage compressor can be used where compression ratios are less than 10:1. Higher compression ratios require a two-stage compressor.

In this example, a larger two-stage compressor would be needed. Since the compressor would become very hot at the interstage, additional compressor cooling (such as fans or expansion valves) would be required. The load on the compressor would be severe, due to the double compression needed to achieve the high condensing pressure.

Service technicians often overlook compression ratio as a possible cause of compressor failure. A dirty condenser can result in high head pressure, which seriously affects compression ratio. Likewise, a very low suction pressure also affects the ratio.

Two-stage compressors are more complicated and more costly than a regular single-stage compressor. The two-stage compressor uses a piston in one cylinder to compress the suction gas to a certain level (first-stage compression), then discharges it into a second cylinder for further compression (second-stage compression). The fully compressed gas exits the compressor through the hot gas discharge line for travel to the condenser. Two-stage compressors usually require special cooling treatment. The need for a two-stage compressor can usually be avoided by selecting another refrigerant that operates within the 10:1 ratio.

REFRIGERANT APPLICATIONS

For general purposes, all refrigeration systems are divided into three temperature ranges: high, medium, and low. An example of high-temperature application is air conditioning. These systems are designed to maintain building interiors at Fahrenheit temperature levels in the 70s, which is considered high temperature for refrigeration systems.

Medium temperature applications use Fahrenheit temperatures in the 30s. Examples would be: domestic refrigerators, dehumidifiers, commercial walk-in coolers, dairy cases, meat cases, and produce cases.

Low-temperature applications usually refer to frozen food and ice cream storage freezers that operate in a range of from 5°F to -50°F (-15°C to -46°C). Still lower temperatures are possible, and are usually referred to as ***ultra-low***, from -50°F to -250°F (-46°C to -157°C) and ***cryogenic***, from -250°F to -460°F, or absolute zero (-157°C to -273°C).

R-22 is a very good refrigerant for high-temperature applications (air conditioning), but is not good for medium- or low-temperature applications. R-12 is an excellent medium-temperature refrigerant, but is not practical for low temperature uses. Compression ratio is the deciding factor in refrigerant suitability. For example, at low temperatures, R-12 must operate with the suction pressure in a vacuum and the Btu/lb. is quite low. R-502 has become the refrigerant of choice for low-temperature applications because of its lower boiling point, higher suction pressure, lower compression ratio, and Btu/lb. (heat value). See Fig. 12-18.

EXPENDABLE REFRIGERANTS

Expendable refrigerants are used primarily for fast freezing at temperatures below -140°F (-96°C). Generally, expendable refrigerants are classified in the cryogenic range, because of their very low boiling points. Refrigerants such as liquid nitrogen or liquid carbon dioxide are sprayed into a freezing chamber and the vapor released to the atmosphere, Fig. 12-19. Such refrigerants are used only once. The vapor is not collected and recondensed as it is in compression systems. Expendable refrigerants must have a very low boiling point. Systems that use expendable refrigerants are sometimes referred to as "open- cycle refrigeration" or "chemical refrigeration" systems.

CRYOGENIC REFRIGERANTS

The use of cryogenic fluids in food manufacturing processes is becoming quite common. A typical cryogenic fluid is liquid nitrogen (R-728), which has a boiling point of -320°F (-196°C) at atmospheric pressure. Liquid carbon dioxide (R-744) is also acceptable as a cryogen, even though its boiling point is -109°F (-78°C) at atmospheric pressure. Other less common cryogenic fluids are:

- Liquid hydrogen (R-702), boiling point -423°F (-253°C)
- Liquid helium (R-704), boiling point -452°F (-269°C)
- Liquid oxygen (R-732), boiling point -297°F (-183°C)
- Liquid air (R-729), boiling point -313°F (-192°C)

Containers for cryogenic fluids are made of special materials that retain their strength at very low temperatures. These containers are heavily insulated and are constructed on the principle of a vacuum bottle. They are never sealed tight, because the vapor must be permitted to escape. The slow, constant boiling of the liquid to a vapor maintains the very low storage temperature inside the container. (The heat for boiling is extracted from the remaining liquid.)

MODERN FREEZING METHODS

Until recently, commercial and industrial food freezing was not well-advanced. Modern technology has produced methods which greatly improved the quality of the finished product. Many food products spoil easily and cannot be stored for any real length of time without suffering loss in quality. Deterioration results from changes within the food caused by micro-organisms, chemical, and biochemical processes. Modern freezing methods play a vital role in controlling these changes, since bacterial and chemical action is greatly retarded by lower temperatures.

It is important to understand the difference between *freezing* and *frozen storage*. ***Freezing*** is actually the

REFRIGERANT APPLICATIONS

NUMBER & NAMES	CYLINDER COLOR CODE	CHEMICAL FORMULA	APPLICATION
R-11 (CFC)	ORANGE	CCl_3F (Trichloromonofluoromethane)	Large-scale air conditioning and refrigeration systems employing single or multi-stage centrifugal compressors. Also used as solvent and blowing agent for foams.
R-12 (CFC)	WHITE	CCl_2F_2 (Dichlorodifluoromethane)	Most popular of all refrigerants, widely used for air conditioning and refrigeration equipment. Also used as blowing agent for foams.
R-13 (CFC)	GRAY	$CClF_3$ (Chlorotrifluoromethane)	Used in the low stage of cascade systems to provide especially low evaporator temperatures.
R-22 (HCFC)	GREEN	$CHClF_2$ (Monochlorodifluoromethane)	Used for low temperature applications such, as room air conditioners and home freezers, and for industrial equipment requiring very low temperatures.
R-113 (CFC)	PURPLE	$C_2Cl_3F_3$ (Trichlorotrifluoroethane)	Low pressure, may be used for centrifugal compressor systems.
R-114 (CFC)	DARK BLUE	$C_2Cl_2F_4$ (Dichlorotetrafluoroethane)	Used with centrifugal compressors when higher capacity or lower evaporator temperatures are needed. Also useful for rotary compressors in small appliances. Volume of vapor circulated per ton is about three times that for R-12.
R-123 (HCFC)	DARK GRAY	$CHCl_2CF_3$ (Dichlorotrifluoroethane)	As a leading candidate in the next generation of blowing agents. HCFC-123 may offer effective solutions in such diverse applications as rigid board and foam systems insulation. Also may be used in centrifugal refrigeration equipment and in specialized solvent applications.
R-134a (HFC)	LIGHT AQUA	CF_3CH_2F (Tetrafluoroethane)	A hydrofluorocarbon with an ozone depletion potential of zero, HFC-134a holds great promise as a CFC substitute for a wide range of air conditioning and refrigeration systems in residental, commerical, and industrial applications.
R-500 (CFC)	YELLOW	CCl_2F_2/CH_3CHF_2 Azeotropic Mixture (Dichlorodifluoromethane/Difluoroethane)	Similar to R-12, R-500 generally has higher discharge temperature range, increased refrigerating capacity.
R-502 (CFC)	ORCHID	$CHClF_2/CClF_2CF_3$ Azeotropic Mixture (Monochlorodifluoromethane/ Monchloropentafluoroethane)	Low temperature commerical and industrial equipment. Used only with reciprocating compressors.

Fig. 12-18. This table summarizes major applications for the most common halide refrigerants.

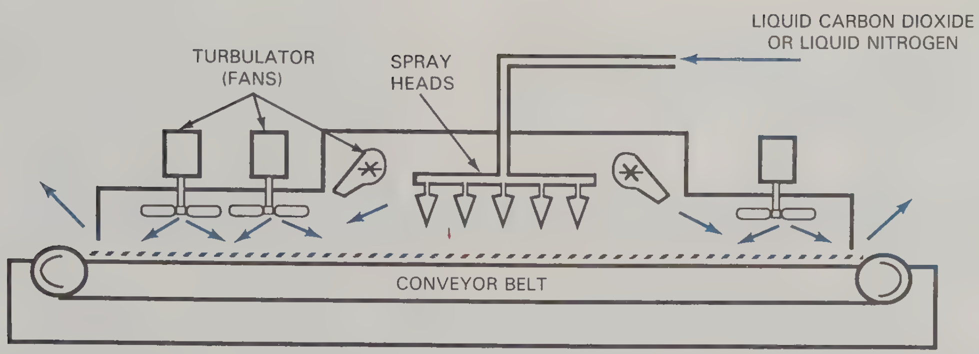


Fig. 12-19. Expendable refrigerants, such as liquid carbon dioxide or liquid nitrogen, are used for rapid freezing in the food processing industry. Since they are actually components of atmospheric air, the refrigerant gases can be released after use without any danger to the environment.

process by which the product's water content is changed to ice and its temperature is lowered to the desired level for storage. ***Frozen storage*** is the storage of an already frozen product at a constant temperature, usually 0°F (-18°C) or lower.

Because water expands when it changes state to a solid, slow freezing of food results in large ice particles. Expansion of the ice damages food fibers, destroys flavor, and decreases shelf life. *Fast* freezing, however, greatly reduces ice expansion.

Fast freezing is done at very low temperatures, using cryogenic refrigerants and equipment installed directly in the production line (called ***in-line freezing***). The foodstuffs are then packaged and placed in frozen storage, which use common refrigerants and the compression refrigeration system. A storage room should not be considered as equipment for freezing, even though it is sometimes used for this purpose.

All frozen food placed in storage should be properly wrapped to prevent loss of moisture. Moisture in exposed foods will *sublime* (see Chapter 3), resulting in a condition known as freezer burn. Freezer burn destroys quality and flavor.

RESPIRATORY DANGERS

The hazard presented by low concentrations of fluorocarbon refrigerants is minor, but the possibility of injury (or death) exists in unusual situations or if materials are deliberately misused. The vapor is almost odorless and is five times heavier than air. Heavy accumulations will displace atmospheric air and prevent access to oxygen. Good ventilation should be provided to eliminate high concentration of vapors.

Becoming light-headed (dizzy) is a warning that oxygen is not available. Anyone suffering from light-headedness should immediately move, or be moved, to fresh air. The use of epinephrine and similar drugs while working with refrigerants should be avoided, because severe heart problems could result. Confined areas should be checked with a leak detector before entering. Service technicians have died from entering tunnels and other areas where heavy concentrations of halide refrigerants had displaced the oxygen. Leak detection procedures are explained in Chapter 13.

SUMMARY

The importance of knowing the physical properties of refrigerants cannot be overemphasized. This chapter has presented this important information and discussed the growing concern over ozone depletion in the earth's atmosphere. The principles involved in selecting a refrigerant for a particular system and the operating characteristics for each of the common refrigerants were discussed.

The technician must understand the principles involved in selecting a refrigerant for a particular system, and be aware of the operating characteristics for each of the common refrigerants. This knowledge is very useful when troubleshooting, repairing, or installing a system. The circulating refrigerant is the key to the entire system. All system problems can basically be reduced to either:

- Poor or nonexistent circulation of refrigerant.
- Not enough refrigerant in the system.

Also explained in the chapter was how to use the saturation tables and how to determine superheat and subcooling. Knowing the differences between refrigerants is necessary to becoming a successful user of these compounds. Knowing how and why a particular refrigerant was selected eliminates problems and mistakes.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name some qualities that will determine a good refrigerant.
2. What are the two basic problems of refrigeration systems?
3. Name the first halide refrigerant.

4. What are the color codes for containers used for refrigerants R-12, R-22, R-500, and R-502?
5. What is the chemical name for refrigerant R-12?
6. Monochlorodifluoromethane is the name for refrigerant ________.
7. Write out the chemical formula for R-22.
8. What are the boiling points of R-12 and R-22 at atmospheric pressure?
9. The chemical elements chlorine and fluorine are known as ________.
10. The halogenated refrigerants are so stable that their condition at every point in the refrigeration system can be ________ and ________.
11. Name two commonly used azeotropic refrigerants.
12. Refrigerant R-502 can absorb ________ more moisture than R-12 without serious system problems.
13. The service technician should never ________ or attempt to ________ refrigerants.
14. What are the "standard conditions" used to compare refrigerants?
15. What is the gauge pressure for refrigerants R-12, R-22, R-500, and R-502 at 10°F?
16. What is the temperature of R-12 at a pressure of 2.32 in. Hg?
17. The best choice of refrigerants is one that has ________ capacity and ________ power requirements.
18. How is the compression ratio calculated?
19. Compression ratios higher than 10:1 usually require a ________ compressor.
20. Give one example each of high-, medium-, and low-temperature applications.

Chapter 13

TROUBLESHOOTING REFRIGERANT PROBLEMS

After studying this chapter, you will be able to:

- *Identify and cure contamination problems.*
- *Detect refrigerant leaks, using approved methods.*
- *Use refrigerant cylinders properly.*
- *Predict and correct low-side pressures.*
- *Recognize and eliminate causes of high head pressure.*
- *Use electronic scales and graduated cylinders for charging.*

NEW WORDS

acids
air off
air on
air space
balance point
black oxides
charging
contaminants
dehydrate
disposable cylinders
electronic leak detector
electronic scale
graduated cylinder
halide torch
head pressure
heat load
hydrostatic expansion
inert
liquid charging
nonflammable
permeation
pressure control
pressure regulator
red iron oxide
returnable cylinders
set point
sludge
soluble
standing pressure test
td
thermostat
vapor charging
working pressure

MOISTURE, AIR, AND CONTAMINANTS

Troubleshooting refrigerant problems involves keeping the refrigerant pure and clean, locating and repairing system leaks, and adjusting system pressures. Moisture, air, and contaminants are major causes of problems in compression refrigeration systems. These systems are designed to operate with a single pure refrigerant. *Air* in the refrigeration system causes high head pressure and high operating temperatures. Sludge, acid, corrosion, and other ***contaminants*** cause various system problems. Acid, for example, eats the insulation off motor windings, causing a burnout. Excess *moisture* in a refrigeration system can cause ice to form, restricting metering devices and preventing proper refrigerant flow. Moisture also causes rusting, corrosion, refrigerant decomposition, oil sludge, and system deterioration.

HOW MUCH MOISTURE IS SAFE?

All fluorocarbon refrigerants will safely tolerate small amounts of moisture. Nobody knows for sure how much moisture is "safe," but there is general agreement that the less water present, the better. Water is more ***soluble*** (easily dissolved) in some refrigerants than others. Any excess water will exist as a separate liquid in the system. If the temperature is low enough, the water will freeze.

The solubility of water in refrigerants is measured in parts per million (ppm), and will vary according to temperature. R-12 is *very* sensitive to moisture–it will only hold 6 ppm by weight. R-502 will hold twice as much

moisture (12 ppm); R-22 will absorb three times more than R-12 (19.5 ppm).

AIR AND MOISTURE REMOVAL

Air and moisture are the primary enemies of a refrigeration system. Proper evacuation and the use of driers are necessary for trouble-free operation.

Thorough evacuation of the system should be performed whenever it has been contaminated or exposed for prolonged periods to moisture-laden atmospheric air. Blowing the system out with an inert gas (nitrogen or CO_2) will remove most of the air from the system, but will not remove air and moisture from trapped areas. Filter-driers will remove small amounts of moisture and contaminants.

Evacuating a system

Before evacuation, the system's internal pressure must be reduced to atmospheric (0 psig). This is necessary because the vacuum pumps used to evacuate systems are not designed to handle pressures above atmospheric.

Proper evacuation of a system is performed with a good two-stage, rotary-type vacuum pump. The vacuum pump draws all vapor (gas) out of the system, reducing its internal pressure to a very low vacuum. The vacuum causes any moisture to boil, allowing it to be removed as a gas.

The amount of time required to properly evacuate a system is strictly a matter of judgment: a large system will require more time on the vacuum pump than a small system. Time must be allowed for the pump to pull a vacuum in all parts of the system, and for moisture to work its way out of oil in the compressor crankcase.

A large quantity of moisture in a system cannot boil into a vapor immediately upon lowering the pressure (just as an open pan of water does not immediately flash into a vapor upon reaching the boiling temperature of 212°F). The boiling process requires time for the molecules to rearrange themselves into a new pattern. The boiling process must continue until all the molecules are rearranged. Stopping the vacuum pump too soon will leave moisture in the system.

Evacuation of the refrigeration system should be performed using a vacuum pump of the proper size. Vacuum pumps are rated in cfm (cubic feet per minute). The following are suggested minimum vacuum pump ratings for systems of different sizes:

Up to 7 tons	1.2 cfm
Up to 21 tons	3.0 cfm
Up to 35 tons	5.0 cfm
Up to 70 tons	10.0 cfm
Up to 105 tons	15.0 cfm

The time required for a vacuum pump to remove air and moisture from a system depends upon several factors:

- Size of the system.
- Amount of water present in the system.
- Capacity of vacuum pump being used.
- Size and length of connecting lines.

Pulling a good vacuum on the system is not sufficient; the vacuum pump must be given time to do its work. The gauge reading reveals pressure at the pump, but seldom shows actual vacuum at the farthest point of the system. The exact amount of time required to evacuate and ***dehydrate*** (dry out) a given system cannot be predicted, because of the many factors involved.

Speed of moisture removal can be increased by applying a heat lamp to the compressor crankcase during the vacuum-drawing process. Severe moisture problems may require the use of heat lamps on other system components, as well. See Fig. 13-1.

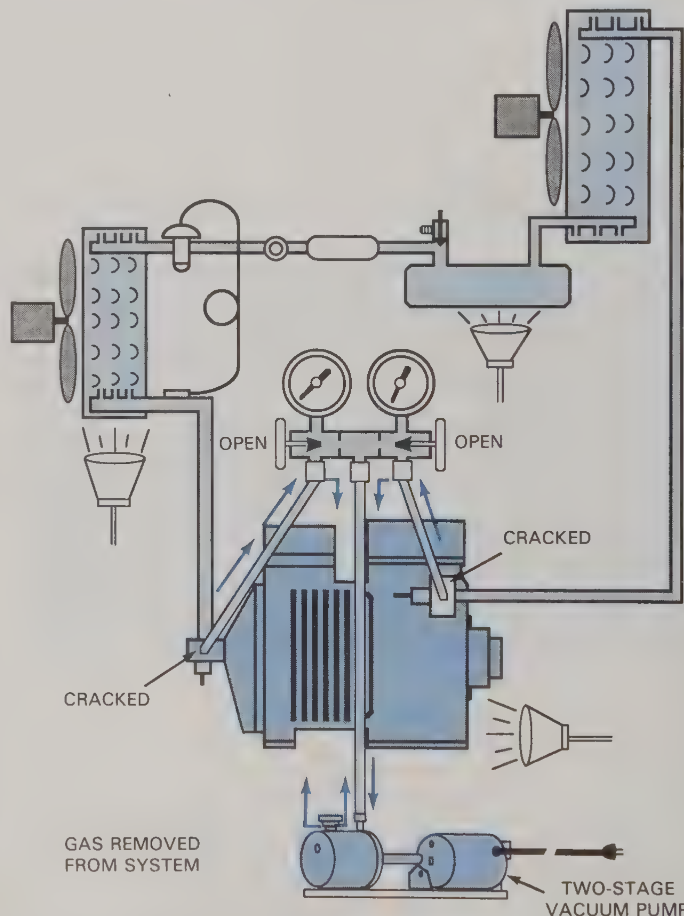


Fig. 13-1. Heat lamps may be used to help drive off moisture when evacuating a system. Typically, a heat lamp would be applied to the compressor, but in severe moisture situations, lamps may also be used at the liquid receiver, the evaporator outlet, and other points.

CONTAMINANTS

In addition to air and moisture, refrigerating systems can be harmed by contaminants such as soldering fluxes, metal chips, wax, acid, oil sludge, dirt, black oxides, and rust. With hermetic and semi-hermetic compressors, the motor windings are exposed to contaminants

in the system. This requires care to avoid contamination. Contaminants cause serious problems to the motor windings.

Sludge is caused by a chemical breakdown of oil that combines with other materials, such as carbon, metals, oxides, or salts. These compounds form a dark, gummy mass that blocks valves, oil ports, screens, and filters. Sludge problems can be traced to high compressor discharge temperatures and the presence of contaminants, including air.

Air in the system causes high discharge pressure (and high temperature). *Atmospheric air* is a source of oxygen and moisture. Oxygen and moisture contribute to breakdown of the oil-refrigerant mixture. This breakdown forms ***acids***, which are corrosive chemical compounds. Acids are more corrosive in the presence of moisture than in a dry system, reacting quickly with metal parts and contributing (among other effects) to the formation of sludge. Therefore, it is important to keep systems as clean and dry as possible.

When there are contaminants in a system, ordinary operating temperatures will produce corrosion. Oxygen from the air and moisture combine to form ***red iron oxide*** (rust). This leads, in turn, to the formation of iron salts and more water if acid is present.

Soldering fluxes also cause metal salts to form. Methyl alcohol (used as an antifreeze) can react with aluminum and cause corrosion. Poor brazing practice can introduce flux (acid) into the system.

Contamination during brazing

Brazing procedures can cause ***black oxides*** to form on the inside and outside of copper tubing. Oxides forming on the outside of tubing cause no harm, but those that form on the *inside* are easily washed from the tubing surface when the system is put into operation. The oxides are then free to circulate with the refrigerant and oil. These oil-borne oxides are exposed to high temperatures at the compressor discharge and cause decomposition of the oil and refrigerant (sludge).

Sweeping with inert gas. You can prevent oxide formation on the inside of tubing by sweeping an inert gas through the tubing during the brazing process, Fig. 13-2. Nitrogen and carbon dioxide are examples of gases that are ***inert*** (chemically inactive) and ***nonflammable*** (will not support combustion). The inert gas will push oxygen and other gases out of the tubing and thus prevent oxidation, since without oxygen, oxides cannot form. The nitrogen should flow very slowly, just fast enough to displace the air inside the tubing. A flow of from 1 to 3 cfm (a pressure reading of 2 to 3 psig) is sufficient.

The inert gas is permitted to escape (vented) after passing the brazing area. Venting eliminates the pressure buildup that would otherwise result from the heat of the brazing torch acting on the confined gas. An escape or vent *must* be provided. If pressurized gas is

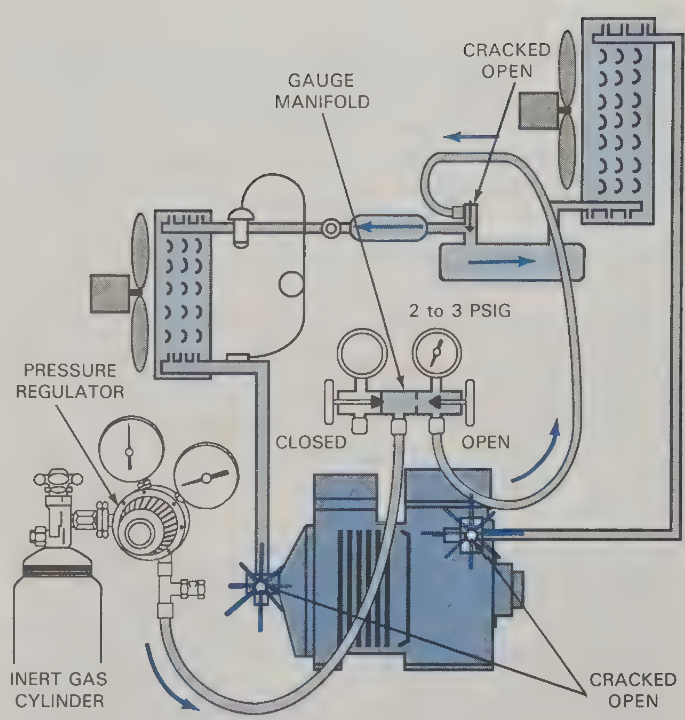


Fig. 13-2. An inert gas, supplied at low pressure, will push ("sweep") atmospheric oxygen out of system tubing to prevent black oxide formation while brazing. The suction and discharge service valves are cracked open to vent the gas and prevent pressure buildup inside the system.

allowed to build up in the tubing, it will blow melted brazing alloy out of the connection.

Gas safety. Nitrogen and carbon dioxide are compressed gases supplied in cylinders under high pressure (2350 psig for nitrogen and about 800 psig for carbon dioxide). Since these pressures are much higher than the 2 to 3 psig needed, you must *always* use pressure-regulating valves on inert gas cylinders. See Fig. 13-3. A

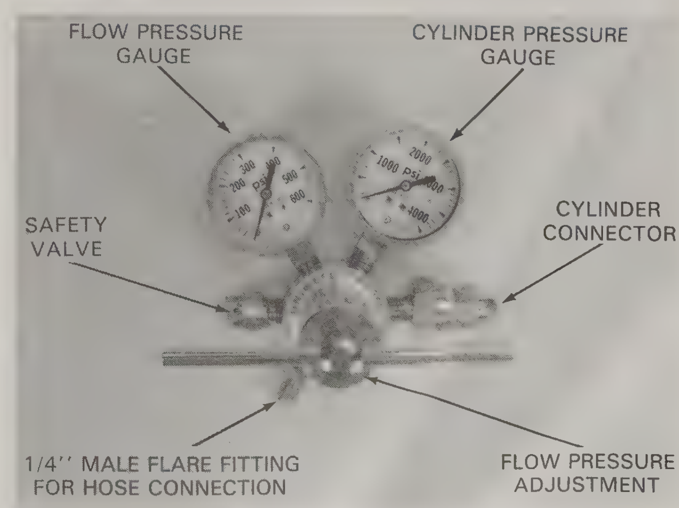


Fig. 13-3. A medium-duty nitrogen regulator capable of regulating output gas flow pressures to between 0 psig and 600 psig. It can be fitted on cylinders filled with gases at up to 4000 psig. (Uniweld)

refrigeration hose (or gauge manifold) is used to transfer the inert gas from the outlet of the flow pressure regulator to the system tubing.

WARNING: Never pressurize a system with oxygen. Oxygen will react violently with oil in the compressor crankcase and explode.

LEAK DETECTION

Locating leaks in refrigeration equipment is a major problem for both manufacturers and service technicians, since refrigerants are expensive and a system cannot operate properly without an adequate supply. Leak detection, however, should be secondary to prevention of leaks. Vibration is probably the principal cause of leaks, but improperly made flared connections or poorly brazed joints are high on the list of contributing factors. Eliminating poor brazing techniques, use of improper fluxes and brazing materials, and poor workmanship will result in fewer leaks.

Sometimes fluxes used for brazing will temporarily prevent a leak by plugging a very tiny hole. When the system is pressurized, however, the flux or residue blows away and a leak develops. Using proper brazing techniques will eliminate this problem.

Repairing a leak is not difficult, but *locating* the leak can prove time-consuming and frustrating. Good technicians are highly skilled in preventing leaks and in locating and repairing them.

Leak detection methods can be divided into two general categories: those used when the system is not charged with refrigerant, and those used when a system already contains refrigerant. They can be referred to as

- GROUP 1: *without* refrigerant.
- GROUP 2: *with* refrigerant.

VACUUM METHOD (Group 1)

In this method, the system is evacuated with a good vacuum pump and both hand valves on the gauge manifold are closed. The vacuum pump is removed, but the system is left in deep vacuum for several hours. If the system maintains the vacuum, you can assume that it is leakproof. If the system loses vacuum, a leak is present and must be located.

This method of leak detection is reliable only for detecting *major* leaks that result in quick loss of vacuum. A partial loss of vacuum might indicate a small leak, or could result from the escape of gases that had been trapped in the oil and were not removed during the vacuum-drawing process. These gases will separate from the oil when left in a vacuum, and will be shown on the gauges as a partial loss of vacuum.

Another problem with the vacuum method of leak detection is the relatively small pressure difference between the inside of the tubing and atmospheric pressure. This pressure difference is only 15 pounds (see Chapter 9), which means that small leaks cannot be readily detected.

Evacuating a system with a vacuum pump requires considerable time and trouble, as described earlier in this chapter. To save time and energy, evacuation should be performed *after* all leak testing is completed, as a necessary preparation for charging the system with refrigerant.

BUBBLE METHOD (Group 1)

The bubble method is the most common and reliable method of leak detection. This requires pressurizing the system with an inert gas to between 150 and 300 psig (1034 and 2069 kPa), then applying a detergent solution to the area being tested. Escaping gas will cause bubbles to appear at the point of the leak. This procedure is simple, but certain precautions must be observed to obtain satisfactory results. The detergent solution must be of the correct consistency and the system must be properly pressurized.

Pressurizing the system

Nitrogen or carbon dioxide are often used to pressurize a system for leak detection. Inert gases like carbon dioxide or nitrogen are not harmful to the system, but the system must *never* be turned on while one or another of them is in the system. A ***pressure regulator*** should always be used with such high-pressure gases to reduce them to a safe ***working pressure*** (test pressure). See Figure 13-4.

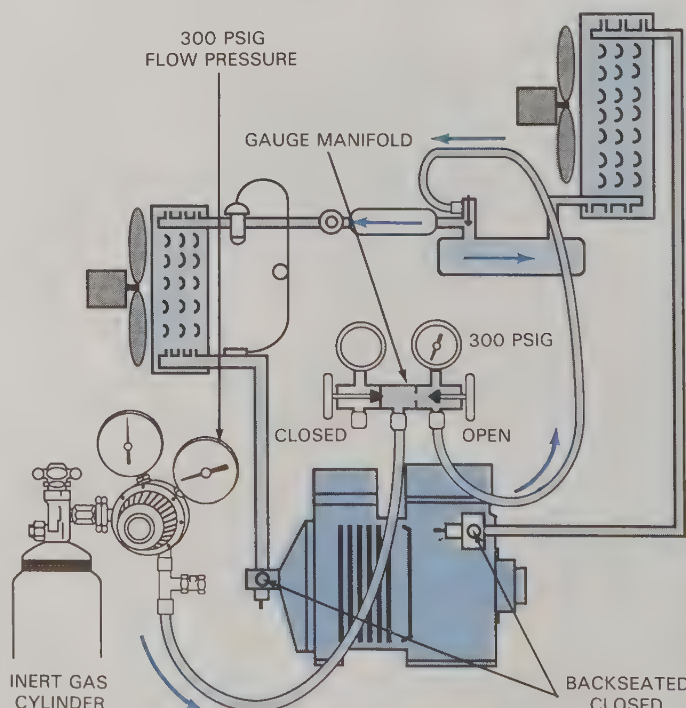


Fig. 13-4. An inert gas, like nitrogen or carbon dioxide, is used to pressurize a system for leak testing. The gas, under 150-300 psig (1304-2069 kPa) pressure, will cause bubbles to form in a detergent solution. This pinpoints the location of the leak. The proper setup for leak-testing a system with inert gas and a detergent solution is shown in this illustration.

For domestic systems using R-12, a test pressure of 150 psig is correct. A test pressure of 300 psig is used for R-22 systems and all commercial systems.

WARNING: Never interconnect a refrigerant cylinder and an inert gas cylinder through a gauge manifold. Accidental opening of the wrong manifold valve would permit high pressure to enter the refrigerant cylinder. High pressure could rupture a refrigerant cylinder, or contaminate the refrigerant.

Detergent solution

A special detergent solution for pressurized leak detection can be purchased from the local refrigeration supply house. This prepared leak detector is available in plastic bottles with a dauber attached to the cap or with a trigger spray. See Fig. 13-5. It is very effective for locating leaks.

An inexpensive detergent solution can be made from concentrated dishwashing liquid. As purchased, these detergents are too thick for proper use in leak detection. They must be thinned by mixing with water in a 1:1 ratio (*equal amounts* of water and detergent). Too much water will make the solution too *thin,* so it will not stick properly or blow bubbles. If the solution is too *thick,* more time will be needed for bubbles to appear (especially on small leaks). The solution must be of proper consistency to adhere (stick) to the surface, but not so thick as to make spraying or bubble-blowing difficult.

Fig. 13-5. Detergent solution for use in the bubble method of leak-testing is available commercially, or can be made as needed, using diluted dishwashing liquid. A trigger-spray bottle with adjustable nozzle permits application in otherwise hard-to-reach areas. (Big Blu)

A handy applicator for detergent solution is a plastic trigger-spray bottle with an adjustable nozzle, like the one shown in Fig. 13-5. The adjustable spray makes it easy to apply detergent solution in a fine stream to points up to four feet away. This can eliminate a great deal of bending, climbing, crawling, and reaching to apply solution in hard-to-reach areas.

When leak testing, apply detergent solution *generously* to suspected leak sites to provide plenty of bubble-forming material. (Solution can be easily wiped up with a cleaning rag after testing is completed.) A large leak will quickly form large bubbles; small leaks will form smaller bubbles, and will do so more slowly. See Fig. 13-6. Be sure to test the gauge manifold and hoses, as well as all system connections.

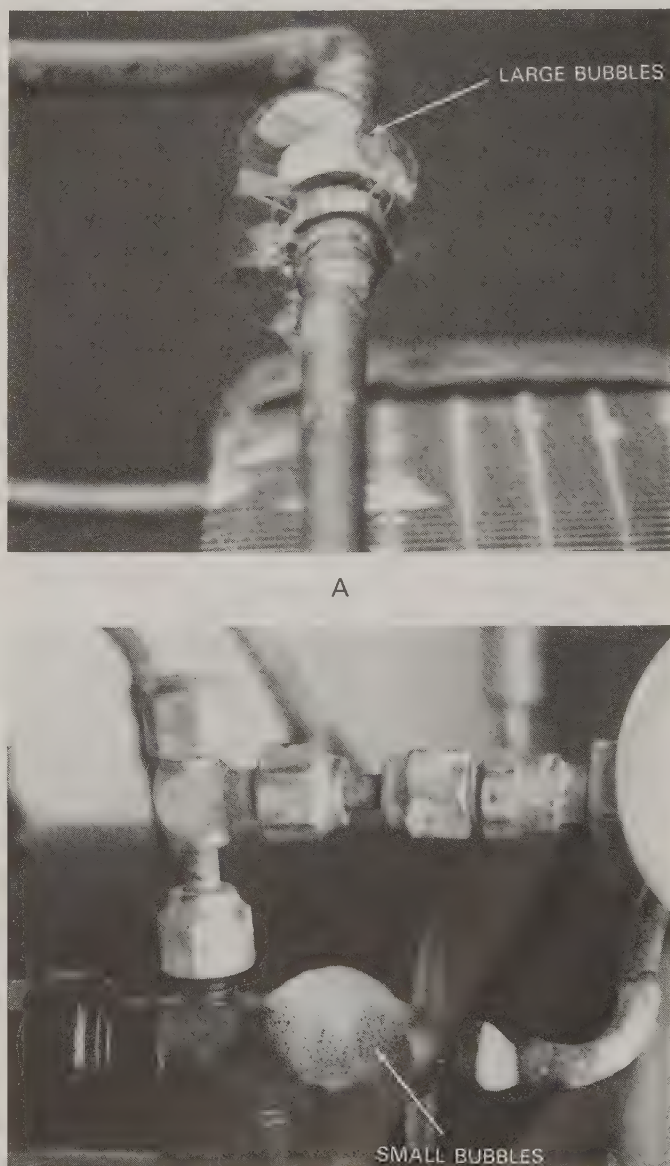


Fig. 13-6. Bubble testing for leaks. A–When a leak is large, bubbles will quickly appear. B–A froth of small bubbles will slowly form at the site of a small leak. (Big Blu)

Ordinary refrigeration hoses may allow gas to seep through their walls (a process called ***permeation***). Heavy-duty hoses do not allow refrigerant loss through permeation.

HALIDE TORCH METHOD (Group 2)

The ***halide torch,*** Fig. 13-7, has been used for many years as a fast and reliable method for detecting halogenated refrigerant leaks. The torch will detect *only* leaking halogenated refrigerants, not other gases such as nitrogen or carbon dioxide.

The halide torch operates on the principle that a flame will change color if it decomposes a halogen in the presence of copper. The essentially colorless flame of the halide torch will change to a color ranging from faint green through bluish green to bright blue, depending upon the size of the leak (and thus the amount of halogen gas being decomposed in the flame). A halide torch is capable of detecting extremely small leaks, such as one that would result in the loss of only one ounce of refrigerant per year.

Hydrocarbon fuels, such as propane, butane, acetylene, or alcohol, are burned in the torch to provide an almost colorless flame. As shown in Fig. 13-8, a copper element is heated by the flame. This does not change flame color by itself–color changes only when the air drawn into the flame contains a halogen. The air is drawn through a "sniffer hose" that is slowly passed over the area of the suspected leak. Any leaking gas will be drawn into the hose, along with atmospheric air, and carried to the flame. Any color changes in the flame will be visible through the viewing window of the torch.

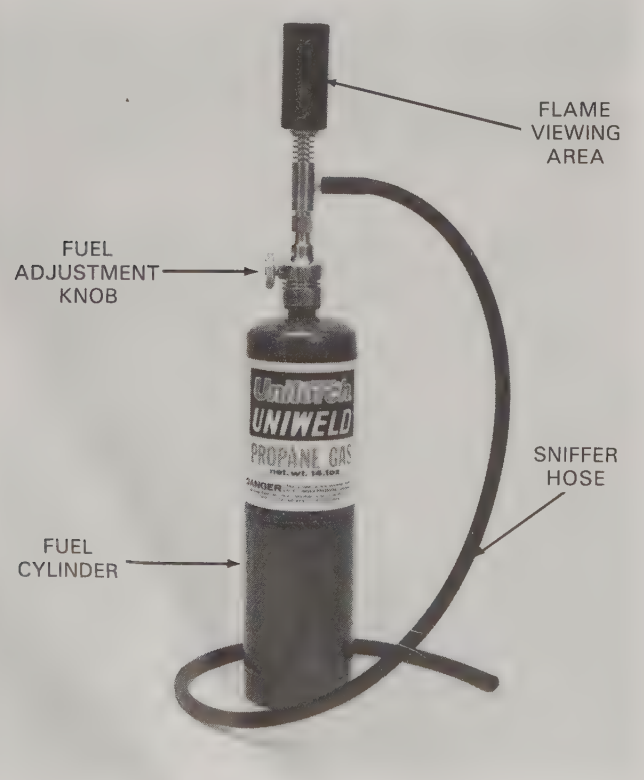


Fig. 13-7. A halide torch used to detect refrigerant leaks. The sniffer hose directs air from the suspected leak site into the torch flame. Changes in flame color make it possible to detect even very tiny leaks. (Uniweld)

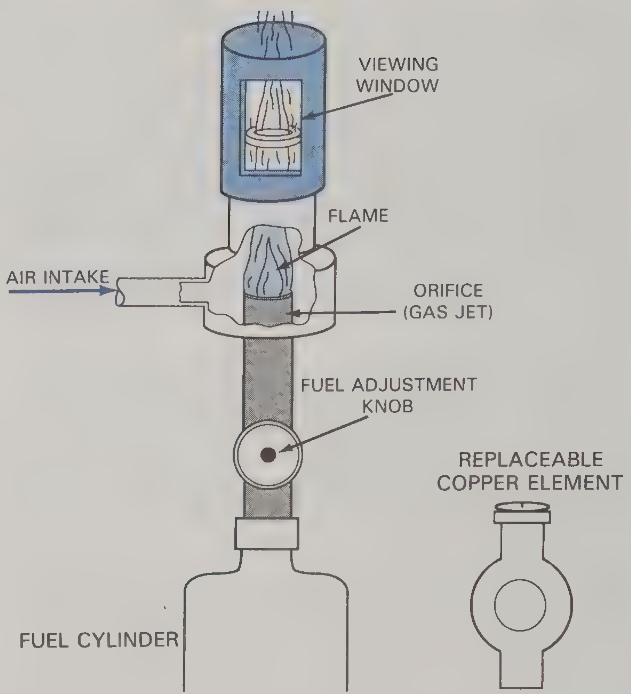


Fig. 13-8. The halide torch consists basically of a flame source, an air intake, a copper element, and a viewing area for flame changes.

Using the halide torch

Since halogen refrigerants are heavier than an equivalent volume of air, they sink downward from the leak site. Since air contaminated with leaking refrigerant can cause false readings in the halide torch, you should always begin checking the system at the top and work downward. See Fig. 13-9. Systematically check each

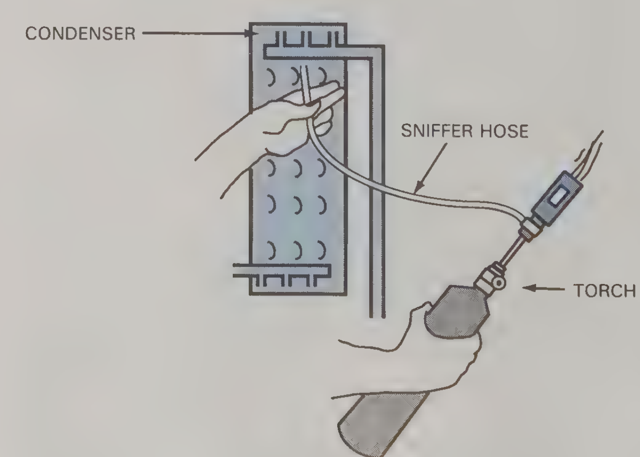


Fig. 13-9. Using a halide torch to check a refrigeration system for leaks. Since refrigerant is heavier than air, begin checking at the top of the system and work downward.

connection or other potential leakage point by slowly passing the sniffer hose over it, while closely observing the color of the flame. Sometimes (especially in areas toward the floor), refrigerant contamination of the air will make it impossible to pinpoint the leak site with the halide torch. Apply detergent solution (the "bubble method") to suspected areas of leakage. Bubble formation will show where the leak is located.

ELECTRONIC DETECTOR METHOD (Group 2)

Small, hand-held electronic detectors are extremely sensitive and easy to use. Most are powered by batteries, but some models must be plugged into a wall outlet for power. As shown in Fig. 13-10, a typical ***electronic leak detector*** consists of a probe and a case containing the electronics. The unit may be equipped with visual indicators, in addition to the audible signal used to indicate the presence of halide refrigerant gas.

In operation, the instrument emits a repeated short "beep" signal. As the probe is passed over the site of the suspected leak, the presence of even a minute trace of refrigerant will cause the sound to change from a repeated one to a long, steady tone.

Like the halide torch, the electronic detector can give false readings because of refrigerant contamination of the air. Unlike the torch, however, the electronic detector can be recalibrated to compensate for a certain amount of atmospheric contamination. It can be made less sensitive, so that it responds only to leaks over a certain volume of flow. This means, however, that it will not identify smaller leaks. At times, it will be necessary to use the same approach as that described for the halide torch: identify the general area of the leak, then apply detergent solution to pinpoint the leak's location.

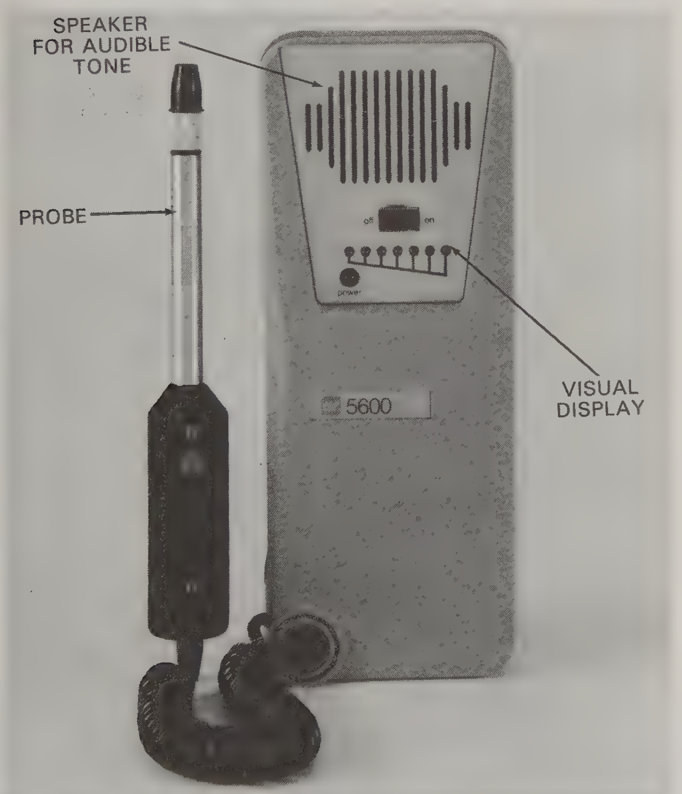


Fig. 13-10. A highly sensitive electronic leak detector. This battery operated model uses an audible tone to signal leaks, and also has a light display to indicate the relative size of the leak. (TIF)

For accurate readings, it is important to keep the sensing probe clean. Check the probe tip regularly for accumulations of lint and dirt. Clean the tip as necessary to keep the equipment functioning properly.

OIL AS A LEAK INDICATOR

Since some oil is always circulating through the system along with the refrigerant, a certain amount will escape at the site of a refrigerant leak. A visual inspection of the system will allow you to detect signs of fresh oil that indicate a leak. Oil spills should always be cleaned up as a safety measure. Cleaning up old oil spills will also make it easier to spot new ones that indicate leaks.

STANDING PRESSURE TEST

Once leaks have been located and repaired, the system should be (if time permits) checked with a ***standing pressure test.*** This will indicate whether all leaks have been fixed.

If the leak testing method was in Group 1 (no refrigerant), inert gas should be replaced as necessary to raise the system pressure to the proper leak-testing level (150 or 300 psig). Note and record the system pressure, then backseat the service valves and remove the gauge manifold. The system is now sealed. After several hours (overnight, if possible), reconnect the gauge manifold, open the service valves, and take a new pressure reading. If it has remained constant, the system has no leaks. Pressure loss indicates that an undetected leak remains.

If the system was tested while containing refrigerant (Group 2 tests), it should be fully charged to bring it to full operating pressure, as described in Chapter 11. Note and record the pressure, then backseat the service valves and remove the gauge manifold. Check the pressure again after several hours (or overnight) to determine whether all leaks were detected and repaired.

REFRIGERANT CYLINDERS

Cylinders used to store and transport refrigerants are made from either steel or aluminum, and are available in a number of standard sizes. All but the smallest of cylinders must have a pressure relief device to protect against excessive pressure buildup. The U.S. Department of Transportation requires either a relief valve or a fusible plug in any refrigerant cylinder more than 12

in. (30 cm) tall and 4 1/2 in. (11 cm) in diameter. On large steel cylinders, a fusible plug is normally located in the concave cylinder base. Depending upon whether a cylinder is used for a corrosive or a noncorrosive refrigerant, it must be inspected every five or ten years.

STEEL CYLINDERS

Large cylinders containing 100 to 150 lbs. (45 to 68 kg) of liquid refrigerant are convenient when servicing systems that require large quantities of refrigerant. They also are less costly, on a per-pound basis, than smaller-size cylinders. Suppliers usually require a sizable deposit to ensure return of the empty cylinder. A steel protective cap is screwed down over the valve at the top of these cylinders when they are being moved or are not in use. See Fig. 13-11.

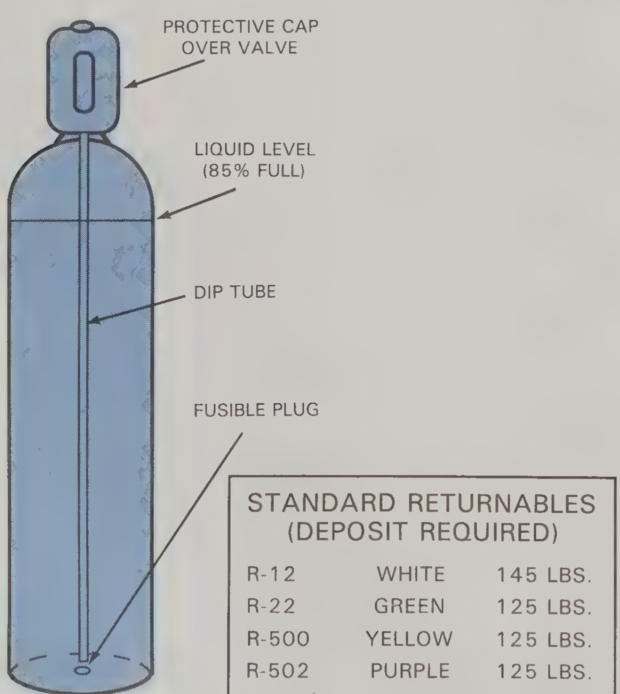
These cylinders are equipped with a dual valve that allows the technician to withdraw refrigerant as a vapor, or by means of a dip tube, as a liquid. There is no need to invert the cylinder (turn it upside-down) to withdraw liquid refrigerant.

A refrigerant cylinder is never completely filled with liquid–space must be left for ***hydrostatic expansion*** (swelling of the liquid) with increases in temperature. A cylinder is considered "full" when liquid occupies 85 percent of its interior space. The remaining 15 percent allows for expansion from a normal range of temperatures without danger of rupturing the cylinder. In case of temperatures that might cause expansion too great for the available space (and thus present the danger of a cylinder bursting), the fuse plug in the base of the cylinder or a special safety valve will open and vent refrigerant to relieve the pressure. See Fig. 13-12.

Saturated conditions exist inside the cylinder, so the contents will behave according to the temperature-pressure chart for the specific refrigerant involved. The space above the liquid is occupied by a very dense refrigerant gas. A *balance point* is reached in which the pressure exerted on the liquid refrigerant by the gas molecules prevents any further *boiling off*, or changing of liquid to the gaseous state.

When the vapor valve at the top of the cylinder is opened, however, the gas molecules can escape. This reduces the pressure on the liquid, allowing it to boil and produce a steady flow of refrigerant gas. This will continue until the valve is closed or all the liquid changes to a gas.

The heat required for the change of state ("boiling off" of gas) is obtained from the remaining liquid and the metal cylinder. As gas is released, both the temperature and the pressure of the remaining liquid will drop. A continuous release of gas will actually cause frost to form on the outer cylinder wall. Cylinder pressure may drop so low that it can create a problem when charging refrigerant into a system in vapor form. The cylinder pressure *must* be higher than the system pressure for vapor to flow from the cylinder into the system. See Fig. 13-13.



STANDARD RETURNABLES (DEPOSIT REQUIRED)		
R-12	WHITE	145 LBS.
R-22	GREEN	125 LBS.
R-500	YELLOW	125 LBS.
R-502	PURPLE	125 LBS.

Fig. 13-11. Large steel refrigerant cylinders are returned to the supplier for refilling after use. The dip tube, used with a special valve, permits the technician to select refrigerant as either liquid or vapor while keeping the cylinder upright. To protect against excessive pressure, a fusible plug is installed in the cylinder bottom.

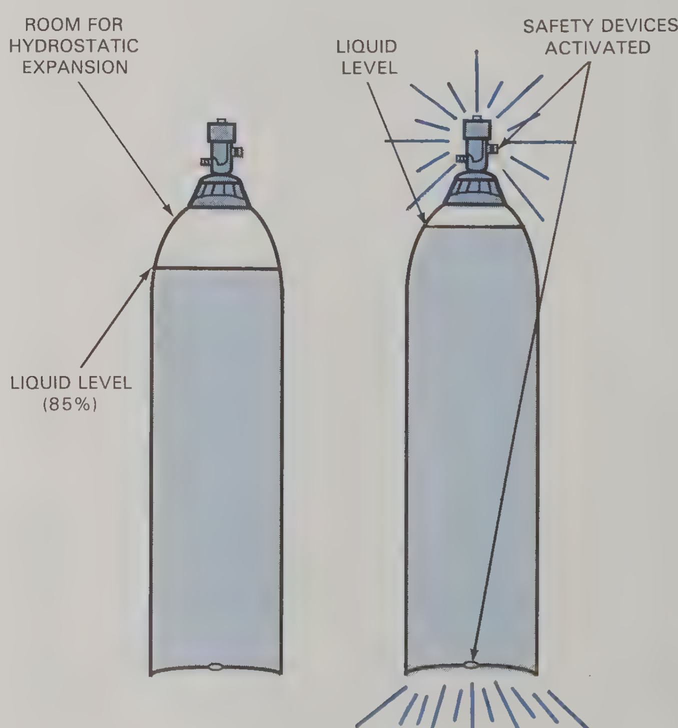


Fig. 13-12. When a cylinder is filled, about 15 percent of its volume must be left for hydrostatic expansion of the liquid refrigerant. If temperature of the cylinder increases to 165 °F (103 °C), fusible plugs will melt or safety valves open to relieve pressure and prevent bursting.

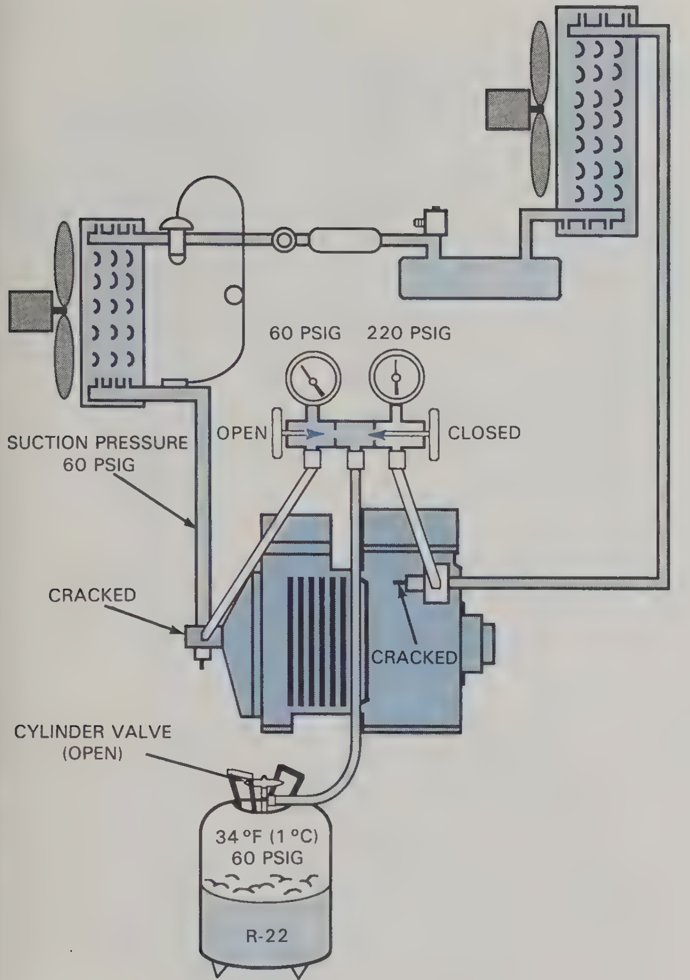
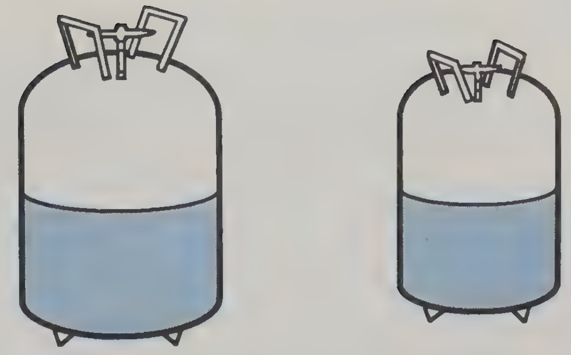


Fig. 13-13. If cylinder pressure is lower than or equal to system pressure, charging will stop. For refrigerant to flow into the system, cylinder pressure must be higher. Pressure can be increased by carefully heating the cylinder.

To increase cylinder pressure in such a situation, the contents can be carefully warmed. The increased temperature will lead to increased cylinder pressure. The best and safest way to increase pressure in the cylinder is to place the cylinder in a container of warm water (80°F to 110°F, or 27°C to 43°C). **Never** heat a cylinder with a torch or use any other heating method that would produce a cylinder temperature greater than 125°F (52°C).

DISPOSABLE CYLINDERS

At one time, industry practice required technicians to transfer refrigerant from large steel cylinders to smaller and more portable steel cylinders holding 25 to 30 lbs.(11 to 14 kg). This time-consuming practice was dangerous and also often resulted in contaminated refrigerant. The introduction of lightweight ***disposable cylinders*** has virtually eliminated the need to transfer refrigerants. These throwaway cylinders, Fig. 13-14, are available in sizes ranging from 25 to 50 lbs. (11 to 23 kg) of liquid refrigerant.



50 LB. DISPOSABLE	
R-12	WHITE
R-22	GREEN
R-500	YELLOW
R-502	PURPLE

30 LB. DISPOSABLE	
R-12	WHITE
R-22	GREEN
R-500	YELLOW
R-502	PURPLE
R-11	ORANGE

Fig. 13-14. Disposable cylinders are light in weight and designed to be discarded after use. They are available in a number of sizes.

Carrying handles on top of the cylinder also serve as protection against damage to the cylinder valve. To withdraw refrigerant vapor, the cylinder is used in the upright position; to withdraw liquid, the cylinder is inverted. See Fig. 13-15. The valve outlet is a 1/4 in. male flare fitting for easy connection to the gauge manifold. **WARNING:** Federal law prohibits refilling disposable cylinders with refrigerant, with violators subject to fines and jail terms. Although it is not illegal, using empty disposable cylinders to transport *compressed air* is unwise: moisture in compressed air could cause the thin metal of these cylinders to rust and eventually rupture.

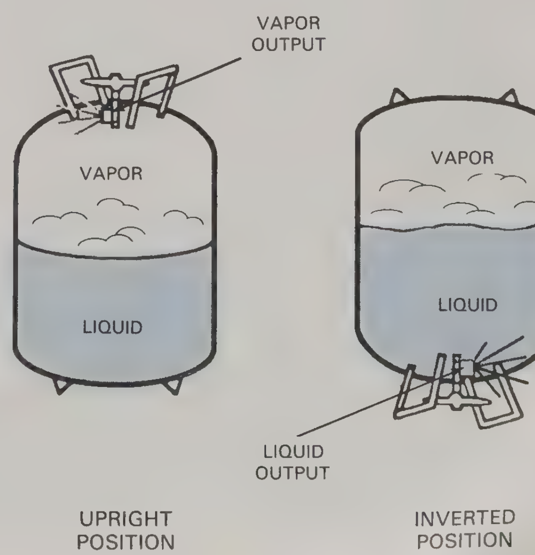


Fig. 13-15. To obtain refrigerant in vapor form, the cylinder is used in the upright position. Inverting it will provide refrigerant in liquid form.

CYLINDERS FOR REFRIGERANT RECOVERY

Since CFCs can no longer be vented into the atmosphere when installing and servicing refrigeration equipment, the use of *returnable* cylinders with refrigerant recovery systems has become widespread.

Returnable cylinders are refillable heavy duty certified pressure vessels meeting U.S. Department of Transportation specifications. Fig. 13-16 shows some typical returnable cylinders. Under federal law, such cylinders must be inspected at regular intervals and repaired or replaced when damaged through handling.

Proper procedures must be followed carefully when using cylinders with refrigerant recovery equipment. The greatest danger to the technician and other nearby persons is overfilling the cylinder with liquid refrigerant. Even though the cylinders have pressure relief devices, they can still rupture or violently discharge refrigerant if overfilled. The amount of liquid refrigerant that a cylinder can safely hold is measured in pounds, which means that quantities will vary by the type of refrigerant (some weigh more than others for a given volume). Sufficient space must be allowed in the cylinder for hydrostatic expansion, Fig. 13-17. Generally, 15 percent of the cylinder's volume should be left empty for expansion.

Cylinders must be clearly labeled with the type of refrigerant they contain, and should always be refilled with the same type. Refilling an R-22 cylinder with R-12 could result in charging a system with the wrong refrigerant. Extreme care should be taken to prevent contamination of refillable cylinders.

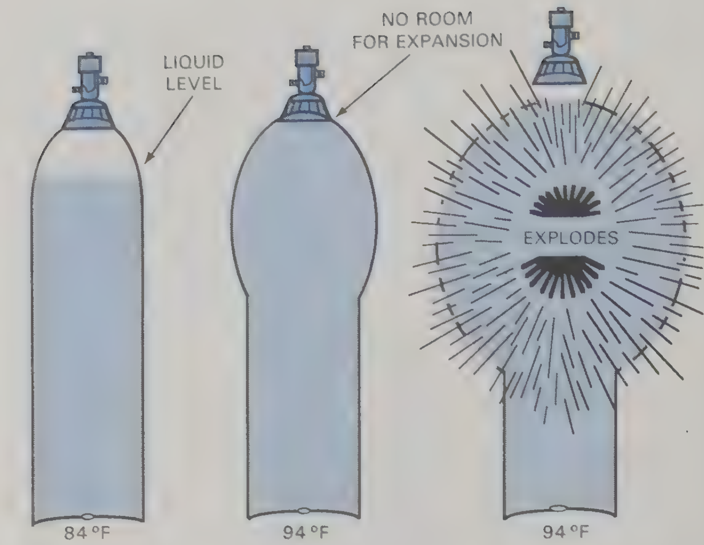


Fig. 13-17. Sufficient room must be left in a cylinder for hydrostatic expansion of the liquid refrigerant. If little or no space is left; an increase in temperature will cause pressure to rise to the point where the cylinder explodes.


Fig. 13-16. Returnable cylinders must meet U.S. DOT specifications and be inspected regularly. This line of cylinders is offered in four sizes: 25 lb., 50 lb., 200 lb., and 1000 lb. (Worthington Cylinder Corporation)

Before being used again, recovered refrigerant should be recycled to separate oil and remove moisture, acids, and foreign particles. Preferably, the refrigerant should go through the *reclaiming* process, which will bring it back to new product specifications.

TEMPERATURE-PRESSURE RELATIONSHIPS

Since refrigerants are pure and stable, temperature-pressure relationships are also stable and predictable. For ease of reference and use, these relationships have been compiled into temperature-pressure or *saturation* charts.

These charts provide a means to quickly convert temperature readings to pressure or vice-versa. A technician can use a manifold gauge to obtain the pressure of the refrigerant in psig, then consult a chart like the handy pocket-sized one in Fig. 13-18 to determine the temperature that corresponds to that pressure. Similarly, when temperature is known, the corresponding pressure can be obtained from the chart. When the system requires a particular temperature, the technician can adjust system pressure after consulting the chart to identify the pressure corresponding to the desired temperature.

When working with systems that use one of the most popular refrigerants (R-12, R-22, or R-502), the technician does not even have to consult the temperature-pressure chart. Instead, he or she can merely check the face of the gauge manifold pressure gauges. As shown in Fig. 13-19, the face of the gauge has several scales: the outer scale shows pressure in psig, while three separate inner scales show the corresponding temperatures

Italics indicate inches Mercury

SATURATION CHART

Bold numbers indicate psig

TEMP.		REFRIGERANT NUMBER AND CYLINDER COLOR CODE									
F°	C°	Silver 717	Orange 11	White 12	Green 22	Purple 113	R123	R134a	Yellow 500	Orchid 502	Aqua 503
-50	-45.6	*14.3*	*28.9*	*15.4*	*6.2*		*29.2*	*18.6*	*12.8*	0.0	86.1
-45	-42.8	*11.7*	*28.7*	*13.3*	*3.0*		*29.0*	*16.6*	*10.0*	2.0	95.2
-40	-40.0	*8.7*	*28.4*	*11.0*	0.5		*28.8*	*14.7*	*7.6*	4.3	108.0
-35	-37.2	*5.4*	*28.1*	*8.4*	2.5		*28.6*	*12.3*	*4.8*	6.7	118.8
-30	-34.4	*1.6*	*27.8*	*5.5*	4.8	*29.3*	*28.3*	*9.7*	*1.2*	9.4	133.0
-25	-31.7	1.3	*27.4*	*2.3*	7.3	*29.2*	*28.1*	*6.8*	1.2	12.3	145.4
-20	-28.9	3.6	*27.0*	0.6	10.1	*29.1*	*27.7*	*3.6*	3.2	15.5	161.0
-18	-27.8	4.6	*26.8*	1.3	11.3	*29.0*	*27.6*	*2.2*	4.1	16.6	166.5
-16	-26.7	5.6	*26.6*	2.1	12.5	*29.0*	*27.4*	*0.7*	5.0	18.1	172.9
-14	-25.6	6.7	*26.4*	2.8	13.8	*28.9*	*27.3*	0.4	5.8	19.5	179.4
-12	-24.4	7.9	*26.2*	3.7	15.1	*28.8*	*27.1*	1.2	6.8	21.0	186.1
-10	-23.3	9.0	*26.0*	4.5	16.5	*28.7*	*26.9*	2.0	7.8	22.6	193.0
-08	-22.2	10.3	*25.8*	5.4	17.9	*28.6*	*26.7*	2.8	8.8	24.2	200.1
-06	-21.1	11.6	*25.5*	6.3	19.3	*28.5*	*26.5*	3.7	9.9	25.8	207.3
-04	-20.0	12.9	*25.3*	7.2	20.8	*28.4*	*26.3*	4.6	11.0	27.5	214.7
-02	-18.9	14.3	*25.0*	8.2	22.4	*28.3*	*26.1*	5.5	12.1	29.3	222.3
0	-17.8	15.7	*24.7*	9.2	24.0	*28.2*	*25.8*	6.5	13.3	31.1	230.0
2	-16.7	17.2	*24.4*	10.2	25.6	*28.1*	*25.6*	7.5	14.5	33.0	238.0
4	-15.6	18.8	*24.1*	11.2	27.3	*28.0*	*25.3*	8.6	15.7	34.9	246.2
6	-14.4	20.4	*23.8*	12.3	29.1	*27.9*	*25.1*	9.7	17.0	36.9	254.5
8	-13.3	22.1	*23.4*	13.5	30.9	*27.7*	*24.8*	10.8	18.4	38.9	263.0
10	-12.2	23.8	*23.0*	14.6	32.8	*27.6*	*24.5*	12.0	19.7	41.0	271.8
12	-11.1	25.6	*22.7*	15.8	34.7	*27.5*	*24.2*	13.2	21.1	43.2	280.7
14	-10.0	27.5	*22.3*	17.1	36.7	*27.3*	*23.9*	14.4	22.6	45.4	289.9
16	-8.9	29.4	*21.9*	18.4	38.7	*27.1*	*23.5*	15.7	24.1	47.7	299.2
18	-7.8	31.4	*21.5*	19.7	40.9	*27.0*	*23.2*	17.1	25/7	50.0	308.8
20	-6.7	33.5	*21.1*	21.0	43.0	*26.8*	*22.8*	18.4	27.3	52.5	318.5
22	-5.6	35.7	*20.6*	22.4	45.3	*26.6*	*22.4*	19.9	28.9	55.0	328.5
24	-4.4	37.9	*20.1*	23.9	47.6	*26.4*	*22.0*	21.4	30.6	57.5	338.7
26	-3.3	40.2	*19.7*	25.4	50.0	*26.2*	*21.6*	22.9	32.4	60.1	349.1
28	-2.2	42.6	*19.1*	26.9	52.4	*26.0*	*21.2*	24.5	34.2	62.8	359.7
30	-1.1	45.0	*18.6*	28.5	54.9	*25.8*	*20.7*	26.1	36.0	65.6	370.6
32	0.0	47.6	*18.1*	30.1	57.5	*25.6*	*20.2*	27.8	37.9	68.4	381.7
34	1.1	50.2	*17.5*	31.7	60.1	*25.3*	*19.7*	29.5	39.9	71.3	393.0
36	2.2	52.9	*16.9*	33.4	62.9	*25.1*	*19.2*	31.3	41.9	74.3	404.5
38	3.3	55.7	*16.3*	35.2	65.6	*24.8*	*18.7*	33.1	43.9	77.4	416.2
40	4.4	58.6	*15.6*	37.0	68.5	*24.5*	*18.1*	35.0	46.1	80.5	428.2
42	5.6	61.6	*15.0*	38.8	71.5	*24.2*	*17.5*	37.0	48.2	83.8	440.5
44	6.7	64.7	*14.1*	40.7	74.5	*23.9*	*16.9*	39.0	50.5	87.0	452.9
46	7.8	67.9	*13.6*	42.7	77.6	*23.6*	*16.3*	41.1	52.8	90.4	465.6
48	8.9	71.1	*12.8*	44.7	80.8	*23.3*	*15.6*	43.2	55.1	93.8	478.5
50	10.0	74.5	*12.0*	46.7	84.0	*22.9*	*15.0*	45.4	57.6	97.4	491.7
55	12.8	83.4	*10.0*	52.0	92.5	*22.1*	*13.1*	51.2	64.1	106.6	517.3
60	15.6	92.9	*7.8*	57.7	101.6	*21.0*	*11.2*	57.4	71.0	116.4	551.8
65	18.3	103.1	*5.4*	63.8	111.2	*19.9*	*9.0*	64.0	78.1	125.8	598.7
70	21.1	114.1	*2.8*	70.2	121.4	*18.7*	*6.6*	71.1	85.8	136.6	
75	23.9	125.8	0.0	77.0	132.2	*17.3*	*4.1*	78.6	93.9	147.9	
80	26.7	138.3	1.5	84.2	143.6	*15.9*	*1.3*	86.7	102.5	159.9	
85	29.4	151.7	3.2	91.8	155.6	*14.3*	0.9	95.2	111.5	172.5	
90	32.2	165.9	4.9	99.8	168.4	*12.5*	2.5	104.3	121.2	185.8	
95	35.0	181.1	6.8	108.3	181.8	*10.6*	4.2	113.9	131.3	199.7	
100	37.8	197.2	8.8	117.2	195.9	*8.6*	6.1	124.1	141.9	214.4	
105	30.6	214.2	11.1	126.6	210.7	*6.4*	8.1	143.9	153.1	229.7	
110	43.3	232.3	13.4	136.4	226.3	*4.0*	10.2	146.3	164.9	245.8	
115	46.1	251.5	15.9	146.8	242.7	*1.4*	12.6	158.4	177.4	266.1	
120	48.8	271.7	18.5	157.7	259.6	0.7	15.0	171.1	190.3	280.3	
125	51.7	293.1	21.3	169.1	277.9	2.2	17.7	184.5	204.0	298.7	
130	54.4		24.3	181.0	296.8	3.7	20.5	198.7	218.2	318.0	
135	57.2		27.4	193.5	316.5	5.4	23.5	214.5	233.2	338.1	
140	60.0		30.8	206.6	337.2	7.2	26.7	229.2	248.8	359.2	
145	62.8		34.4	220.3	358.8	9.2	30.2	245.6	263.7	381.1	
150	65.6		38.2	234.6	381.5	11.2	33.8	262.8	280.7	404.0	

Fig. 13-18. A pocket-sized temperature-pressure chart is a useful reference when adjusting system pressures to achieve desired temperatures. Charts often show pressures for several popular refrigerants; specific charts are available for each refrigerant in commercial use. (Sporlan Valve Co.)

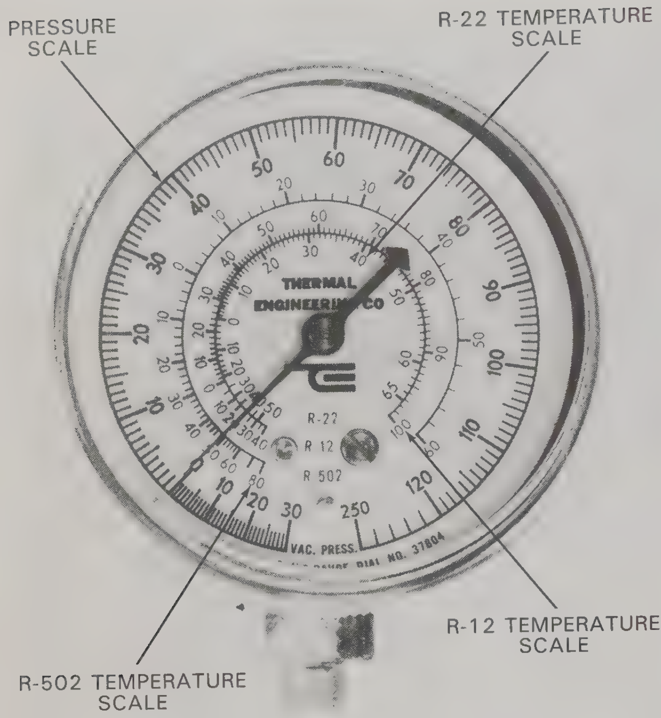


Fig. 13-19. This low-pressure gauge includes corresponding temperature scales for the three most widely used refrigerants. It allows relationships to be read directly from the gauge face, eliminating need to refer to a chart. (Thermal Engineering)

(in °F) for R-12, R-22, and R-502. This allows the temperature- pressure relationship to be read directly from the gauge face. For other refrigerants, or course, the chart must be used to determine temperature for a given pressure.

CONTROLLING LOW-SIDE PRESSURES

The evaporator of an operating refrigeration unit absorbs heat from the space being cooled. The temperature of a product (such as ice cream in a home freezer) is controlled by the temperature of the air circulating around that product. The product gives up its heat to the air, which in turn gives up its heat to the evaporator. The evaporator temperature will be about 10°F (5.6°C) colder than the temperature of the entering air (called "air on").

The evaporator gives up its heat to the boiling refrigerant inside the tubing. The refrigerant is about 10°F (5.6°C) colder than the evaporator. These temperature differences (air-to-evaporator and evaporator-to-refrigerant) must be maintained to accomplish heat removal. See Fig. 13-20.

The amount of heat that must be removed per hour from an enclosed space determines the size of the evaporator that must be used. The correct amount of refrigerant must be boiled to maintain the necessary temperature inside the evaporator, as well. When the air temperature is lowered to the desired level, the refrigeration system is turned off. The temperature differences quickly disappear, and heat removal stops, as shown in Fig. 13-21.

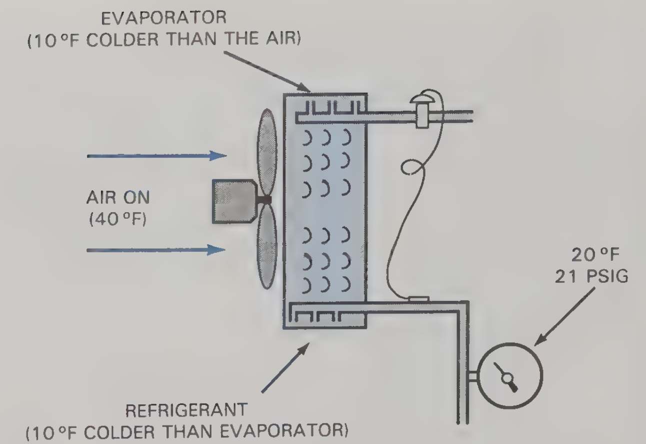


Fig. 13-20. Temperature differences are critical to accomplishing heat removal. The evaporator of an operating refrigeration system will be 10 °F colder than the air of the space being cooled, while the refrigerant inside the evaporator will be 10 °F colder than the evaporator itself. As shown, if the room air (''air on'') temperature is 40 °F, the temperature of the refrigerant at the evaporator outlet will be 20 °F.

The low-side pressure always reveals the *refrigerant temperature*. When the system is not operating, the temperature of the refrigerant, the evaporator, and the room air will be the same, since no temperature difference (*td*) exists. For example, in a system charged with R-12 that has a low-side pressure reading of 37 psig, the refrigerant temperature at the evaporator outlet will be 40°F (4°C). Since the system is not in operation, the temperature of the evaporator will also be 40°F, as will the air temperature. Different refrigerants will have different pressure readings at 40°F (68.5 psig for R-22, and 80.2 psig for R-502), but the principle remains the same.

A refrigeration system is designed to quickly *establish* and *maintain* a temperature difference once it begins operating. For example, in a system that is using R-12 and has a low-side pressure of 15.8 psig, the refrigerant temperature will be 12°F (-11°C). Thus, the tem-

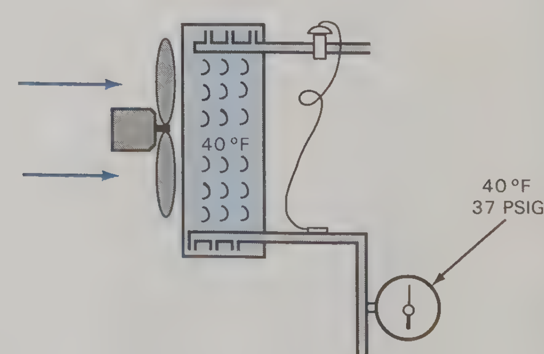


Fig. 13-21. When a refrigeration system is turned off, temperature differences quickly disappear and heat removal stops. Note the air temperature and the temperature of the refrigerant at the evaporator outlet. No heat can flow when a temperature difference doesn't exist.

perature of the evaporator is 22°F (-6°C), and the air temperature is 32°F (0°C). This relative temperature difference remains constant while the system is running: as the entering air becomes cooler, the evaporator and refrigerant temperature drop accordingly. Pressure readings also decrease as a result of the lowered temperatures.

The temperature difference necessary for cooling is obtained only when the system is running. Once the system is turned off, the evaporator and refrigerant temperatures will quickly rise and equal that of air flow. To maintain air temperature within a set range, a ***thermostat*** (temperature-activated switch) may be located within the area being cooled, also known as the ***air space***.

During the "off" cycle, the air temperature is typically allowed to rise five or six degrees. When the air temperature reaches the highest ***set point*** (top of the range for which the thermostat is set), the system is switched on. When the air temperature drops to the lowest set point, the thermostat switches the system off. The air begins to warm again, and the cycle repeats. An example would be a walk-in dairy cooler with temperatures maintained in the 32°F-38°F (0°C-3°C) range. When air temperature rises to 38°F, the cooler's refrigeration system turns on. It runs until the temperature of the air falls to 32°F, then shuts off.

Since the temperature differences allow low-side *pressures* to be predicted and controlled, many refrigeration systems are turned on and off by a ***pressure control,*** rather than a thermostat. The pressure control functions as a switch, turning the system on and off as a result of changing low-side refrigerant pressure to maintain temperatures within the desired range.

Evaporator air flow

To maintain proper temperature differences, there must be the correct amount of air flow across the evaporator. Medium-temperature evaporators require a flow of about 1350 cfm per ton; low-temperature evaporators, about 2000 cfm per ton. Airflow that is lower in volume than required will result in a very cold evaporator with low refrigerant pressure, since the ***heat load*** (air to be cooled) cannot reach the evaporator in sufficient volume. Excessive airflow will place too much heat load on the evaporator, resulting in high temperatures and pressures.

Air conditioner temperature differences

The temperature differences designed for air conditioners are different from those for refrigeration systems. Since humans find large volumes of very cold air uncomfortable, air conditioning evaporators are designed for an airflow of approximately 400 cfm per ton. The evaporator is designed to produce a temperature difference of 16°F-20°F (9°C-11°C) between the air entering the evaporator (referred to as return air or ***air on***) and the air leaving the evaporator (supply air or ***air off***).

Although temperature differences for most refrigeration systems are calculated from air *on*, temperature differences for air conditioning systems are calculated from air *off*. In other words, the temperature of the evaporator will be 10°F (5.6°C) colder than the air *leaving* it, rather than the air entering it. As shown in Fig.13-22, the temperature difference between air off (55°F or 12.8°C) and the evaporator (45°F or 7.2°C) is 10°F or 5.6°C, while the difference between air on (75°F or 23.9°C) and the evaporator temperature of 45°F (7.2°C) is 30°F or 16.7°C.

A supply air (air off) temperature of 55°F (12.8°C)is considered the lower limit for human comfort. As noted, this results in an evaporator temperature of 45°F (7.2°C), and in turn, a refrigerant temperature of 35°F or 1.7°C (at a corresponding pressure of 61.5 psig for R-22). In air conditioning work, common practice is to maintain low-side pressure above 60 psig.

Allowing the *evaporator* temperature to fall to 32°F (0°C) in an air conditioning situation can create cooling problems. At 32°F, moisture in the return air will *freeze* on the evaporator surface. Ice buildup will restrict (or even totally block) airflow through the evaporator.

CONTROLLING HIGH-SIDE PRESSURES

The condensing unit of a refrigeration system has a single task: to convert gaseous refrigerant back into a liquid form for re-use. The cooling medium is usually outside ambient air. Since heat moves from hotter areas to cooler ones, the gas must be *compressed* to a saturation point that will be higher than the temperature of the ambient air. This means that as the outside ambient air temperature goes up or down, the high-side pressure-temperature will follow suit to maintain a temperature difference.

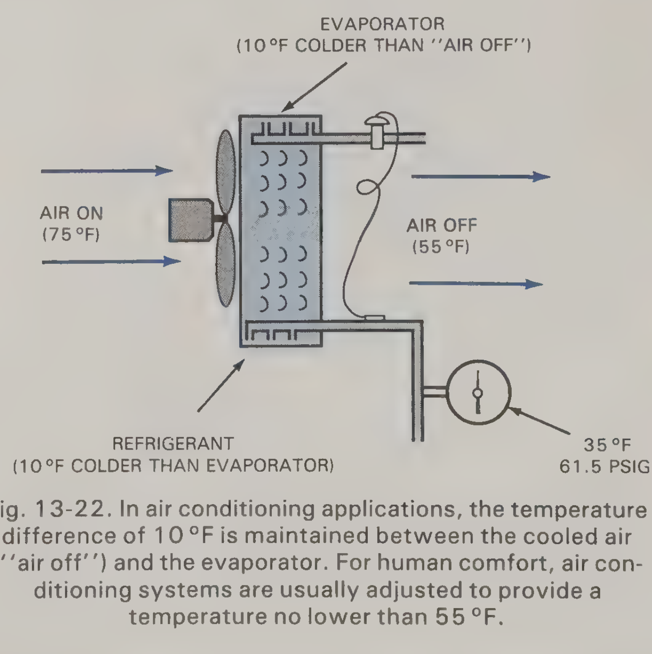


Fig. 13-22. In air conditioning applications, the temperature difference of 10 °F is maintained between the cooled air (''air off'') and the evaporator. For human comfort, air conditioning systems are usually adjusted to provide a temperature no lower than 55 °F.

The system is designed so that the high-side pressure will rise to a saturation point, where the refrigerant gas can be converted back to a liquid state. The rate at which the change of state takes place *must* equal the rate at which gas enters the condenser. This is called the ***balance point.*** The condenser is sized to match system capacity. If the balance point changes, the high-side pressure/temperature will change accordingly.

Air-cooled condensers

The balance point (high-side pressure) of the condenser can be predicted. The compressor must compress the gas to a saturation temperature that is 30°F-35°F (17°C-20°C) above the temperature of the ambient air. With this information and the ambient temperature reading, a temperature-pressure chart can be used to determine proper ***head pressure*** (pressure on the high side of the system).

For example, if the ambient temperature is 70°F (21°C), the temperature of the refrigerant (R-12, in this case) in the condenser should be between 100°F (38°C) and 105°F (41°C). See Fig. 13-23.

If the ambient temperature increases to 95°F (35°C), refrigerant temperature in the condenser should fall between 125°F (52°C) and 130°F (54°C). Normal head pressure at an ambient temperature of 95°F, would thus be between 168 psig and 181 psig.

This method of predicting head pressure is usable for most halide refrigerants. Condensers used with R-502 are more efficient than those used with other common halide refrigerants. Thus, the refrigerant temperature difference from the ambient air temperature is smaller: 20°F-25°F (11°C-14°C). See Fig. 13-24.

Water-cooled condensers

Some refrigeration systems use water-cooled condensers, which are more efficient than air-cooled condensers. Water-cooled condensers remove heat by conduction, which provides better heat transfer. As shown in Fig. 13-25, head pressure should correspond to a temperature of 15°F-20°F (8°C-11°C) higher than the temperature of the water leaving the condenser.

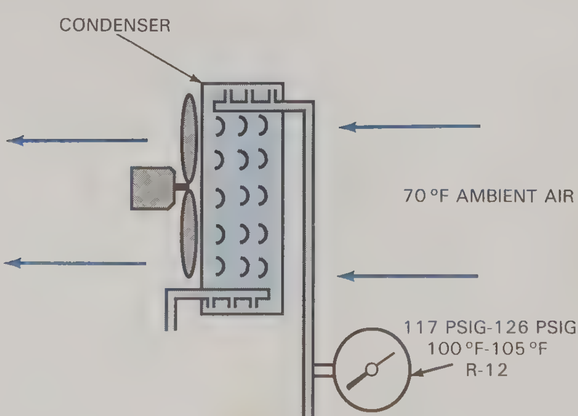


Fig. 13-23. In a balanced system, refrigerant temperature in the condenser will be 30 °F-35 °F higher than the temperature of the ambient air. This fact allows use of a temperature-pressure chart to predict head pressure.

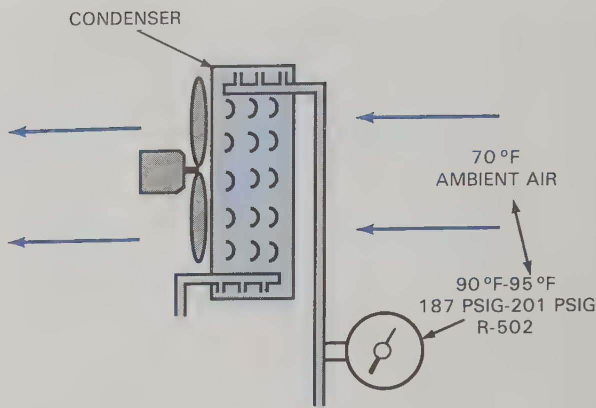


Fig. 13-24. Compressor must compress gas to 20 °-25 ° above ambient air temperature for R-502.

Excessive head pressure

As head pressure increases, the compressor works harder to achieve the balance point. Excessive head pressure should be avoided, since it reduces system efficiency and causes compressor problems.

Higher-than-normal head pressures can be traced to one of five possible causes:

Air in the system. Air is a mixture of noncondensable gases that will behave according to Dalton's Law of Gases (pressures are added together to find total pressure). To achieve normal head pressure, the air must be removed.

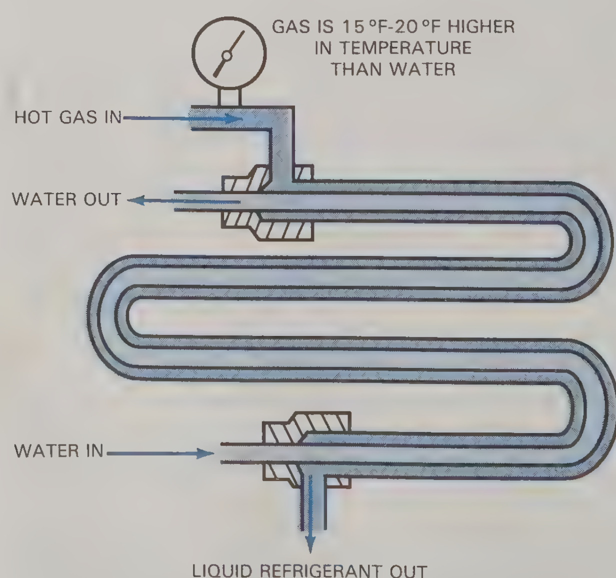


Fig. 13-25. Water-cooled systems transfer heat efficiently by means of conduction, so the refrigerant in the condenser is only 15 °F-20 °F higher in temperature than the water leaving the condenser.

Overcharge of refrigerant. Any excess refrigerant will collect in the condenser. This reduces condenser capacity and raises the balance point.

Dirty condenser. If allowed to accumulate on either an air-cooled or water-cooled condenser, dirt will act as an insulator, reducing condenser capacity and raising the balance point.

Reduced air or water movement. If there is no movement of a heat transfer medium (air or water) past the condenser tubes, head pressure will rapidly rise to an excessive level. Head pressure safety controls are use to prevent damage. Lack of movement in an air-cooled condenser can be caused by a burned-out fan; in a water-cooled compressor, a closed water valve is a possible cause.

High low-side pressure. If the low-side pressure is above normal, the head pressure will also rise. High suction pressure and heat content require the compressor to achieve a higher balance point. System pressures go together: if the high-side pressure goes up, so does the low-side pressure, and vice-versa. The only exception would occur when a compressor is defective: an increase in low-side pressure would not be accompanied by a corresponding increase in high-side pressure.

CHARGING REFRIGERANT INTO A SYSTEM

The term ***charging***, in relation to a refrigeration or air conditioning system, means to add refrigerant. Systems use different kinds and amounts of refrigerant, and the amounts are sometimes critical. In some domestic systems, for example, a one-half ounce overcharge or undercharge can noticeably affect operation. In other systems, there is some room for error: those that use a liquid receiver, for example, can operate with an excess of refrigerant. As a general rule, knowing when to *stop* adding refrigerant to a system is of equal importance to knowing *how* to add refrigerant.

Refrigerant can be charged into a system as a *vapor*, or as a *liquid*. Before it can be charged, a system must be tested for leaks, dehydrated, and evacuated. A gauge manifold can then be connected to the suction service valve and to the discharge service valve. Both connections are important, since they provide necessary pressure readings.

VAPOR CHARGING

The most common form of charging a system is to add refrigerant vapor to the low-pressure side (***vapor charging***). This is done by using the gauge port on the suction service valve. The center hose from the manifold is connected to a refrigerant cylinder, which must be in the *upright* position to permit vapor charging. The cylinder valve is then opened, transferring control to the gauge manifold.

Cylinder pressure *must be higher* than suction pressure, since refrigerant will not flow without a pressure difference. Sometimes, cylinder pressure must be carefully increased by warming the cylinder with hot water. **CAUTION:** Never use a torch to heat a refrigerant cylinder, and never raise cylinder temperature above 125°F (52°C).

With both service valves in the cracked position, open the left (low-pressure side) manifold hand valve. Refrigerant vapor will travel from the cylinder, through the yellow (center) hose and the left side of the manifold to the blue hose and then into the compressor through the suction service valve. See Fig. 13-26.

If the system is turned off, refrigerant can be charged into *both* the high side and the low side by opening both hand valves on the manifold.

WARNING: When the system is running, *never* open the right (high-pressure side) manifold hand valve. Since the system's high-side pressure is greater than the cylinder pressure (see Fig. 13-26), the system will pump into the cylinder. This can contaminate the cylinder and could cause the cylinder to *rupture.* The high-pressure gauge is connected to the discharge service valve to allow monitoring of high-side pressures while charging.

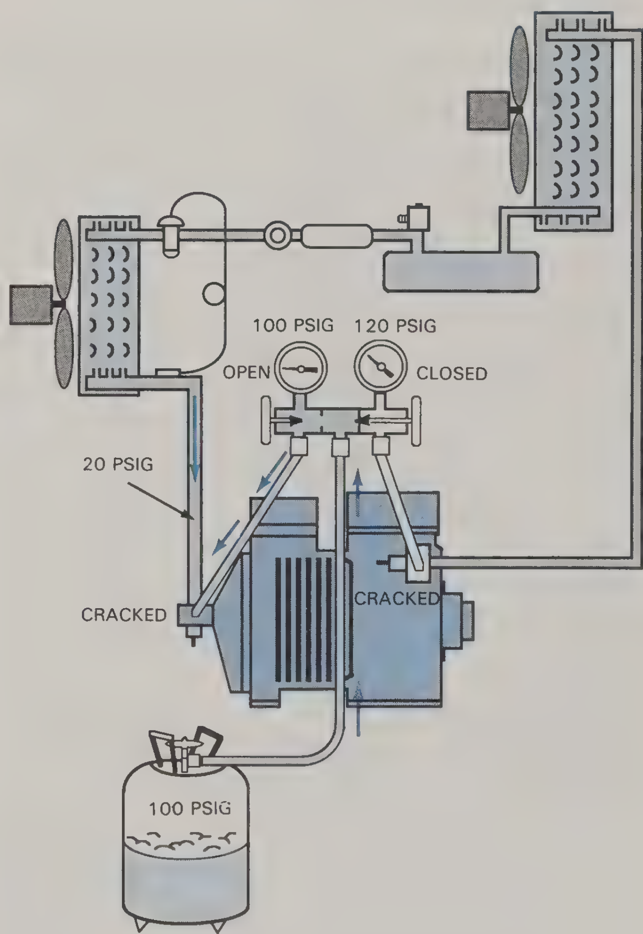


Fig. 13-26. When vapor charging is being done, the refrigerant vapor flows from the cylinder through the hoses to the compressor. Cylinder pressure must be higher than suction pressure, so that the refrigerant vapor will flow into the system.

The process of charging will take longer if done using Schrader valves, rather than service valves. The passage for gas or liquid through a Schrader valve is much smaller than the passage through a service valve. Since the smaller passage restricts refrigerant flow, charging takes longer.

Charging too fast should be avoided, however, since it may cause discharge pressure to rise rapidly (it should not be allowed to exceed normal operating pressure). When charging with vapor, the process must be stopped periodically to check low-side operating pressure. That pressure should correspond to the conditions surrounding the evaporator.

NOTE: System operating pressures will not be normal until the system is fully charged and has achieved normal operating temperatures. Both high-side and low-side pressures will be too low if the system is *undercharged.* If the system is *overcharged,* the high-side pressure will be high. The low-side pressure will be high if the evaporator temperature is high.

Charging of small systems with hermetic compressors should always be done using the vapor method. Liquid refrigerant can easily damage hermetic compressors.

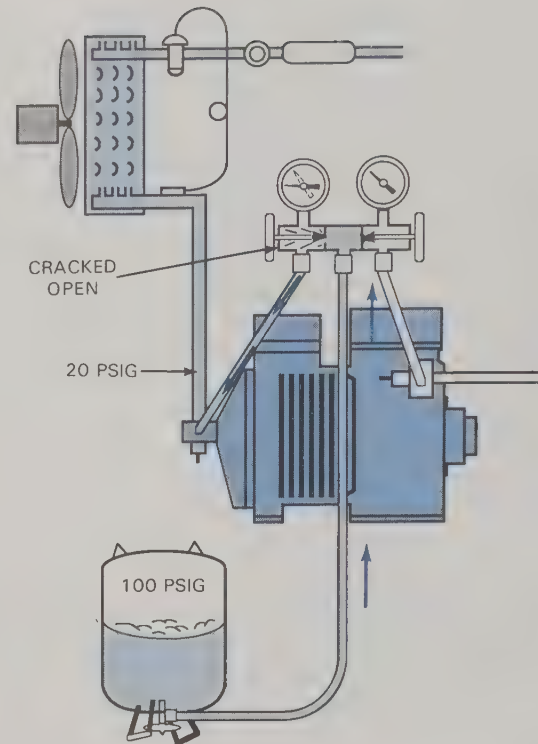


Fig. 13-27. When liquid charging, the technician must be careful to prevent liquid refrigerant from entering and possibly damaging the compressor. Gauge pressure should be 10 psig-15 psig above actual suction pressure.

LIQUID CHARGING

Charging a system with refrigerant in a liquid state is faster than vapor charging, since it is done with the system operating, but requires skill and experience. Since ***liquid charging*** can easily result in overcharging and can cause compressor damage, it should be attempted only by experienced technicians. When liquid charging, the cylinder pressure will remain constant, since the liquid will change state to a vapor *inside the system*, rather than inside the cylinder. For liquid charging, the cylinder is inverted, as shown in Fig. 13-27.

Proper procedure for liquid charging involves *metering* the refrigerant into the low-pressure side of the system by adjusting the gauge manifold. The left (low-pressure) manifold valve is cracked open so that a pressure 10 psig-15 psig higher than suction pressure is maintained. See Fig. 13-27. Frost will form on the manifold body and the hose connected to the suction service valve. Frost should not be allowed to reach the compressor body, since this would indicate liquid refrigerant is present.

Because low-side pressure will increase as refrigerant is added to the system, the left manifold valve should be closed at regular intervals to check pressure. When the valve is closed, frost will disappear, as well. After pressure is checked, the valve should be cracked open once again and the 10 psig-15 psig pressure differential established.

Watch the high-side gauge to avoid excessive head pressure. Observe the sight glass to watch for bubbles. When bubbles disappear from the sight glass and the two gauges register the correct pressure, the system is fully charged.

On larger systems, the liquid receiver service valve is usually used for charging. The valve is front-seated, which causes the system to pump down (evacuate the low side). When liquid is charged into the system through the LSRV valve, it travels to the expansion valve and the evaporator. The liquid becomes a vapor before it reaches the compressor. See Fig. 13-28.

Systems with liquid receivers are purposely overcharged slightly. The technician must determine how much liquid is being stored in the liquid receiver (on very large systems, it may be big enough to hold the contents of three or four 30 lb. cylinders of refrigerant). Periodically, charging should be stopped and the liquid line sight glass checked for bubbles. When they stop appearing, the liquid line is full and the receiver dip tube (outlet) is covered with liquid. Some additional refrigerant is then added to the system, with the amount determined by the technician's experience and good judgment. The size of the receiver, and how much liquid it already contains, must be taken into account.

Charging by weight

Small self-contained systems, such as window-mounted air conditioners, domestic refrigerators, and ice-making machines, are usually charged by weight of refrigerant. The recommended charge is usually stamped on the data plate of the equipment, making it quick and easy to measure an exact amount of refrigerant and charge the system. The system must be thoroughly evacuated before charging.

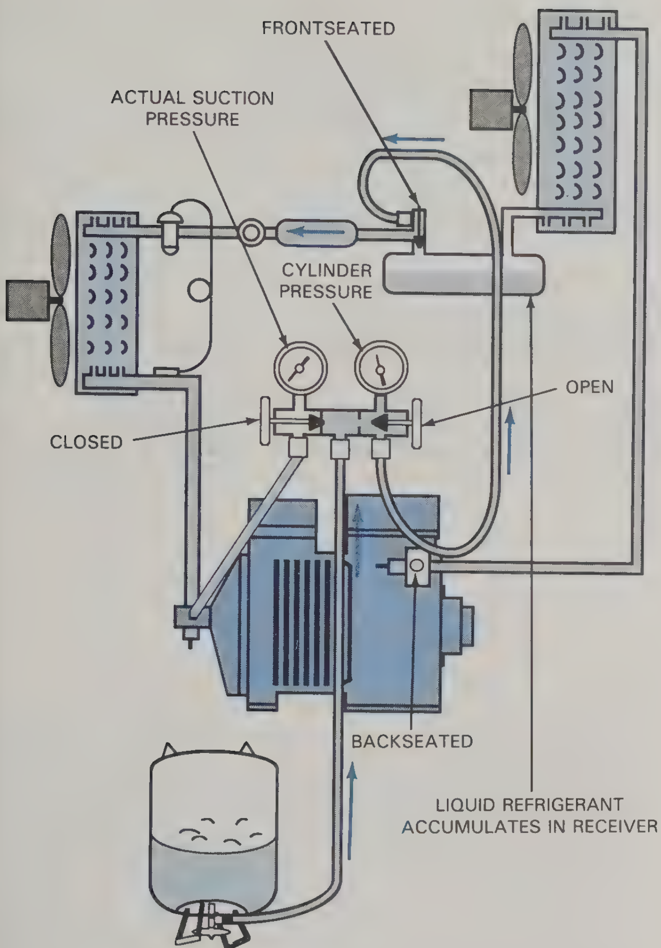


Fig. 13-28. For larger systems, charging is often done through the liquid receiver service valve.

Fig. 13-29. Electronic scales permit very accurate measurement of refrigerant while charging. The cylinder is placed on the scale pad, and the weight readout adjusted to zero. As refrigerant is charged into the system, the readout will keep a running total in pounds and ounces. (Robinair Mfg. Corp.)

Electronic scales. Accurate, easy-to-use weighing devices, Fig. 13-29, are readily available for use by technicians. These ***electronic scales*** have displays that can be set to read zero when a full refrigerant cylinder is placed on them. The display will then show, in ounces, the amount of refrigerant being withdrawn from the cylinder and charged into the system. When the desired refrigerant weight is reached, the manifold hand valve is closed to stop the process.

Graduated cylinder. A very common method of measuring an exact refrigerant charge is the ***graduated cylinder,*** Fig. 13-30. Such cylinders are very accurate, and have scales for measuring three widely used refrigerants: R-12, R-22, R-502. The graduated scales can be rotated to align the desired one with the external viewing tube that shows the liquid level inside the tube.

The graduated cylinder measures refrigerant by volume, rather than weight. Since volume varies with temperature, the cylinder is equipped with a pressure gauge to permit selecting the proper scale. The cylinder is equipped with a top hand valve for vapor charging and a bottom hand valve for liquid charging. See Fig. 13-31.

Before use, the graduated cylinder is charged with liquid refrigerant from a larger cylinder. The liquid

Fig. 13-30. A graduated charging cylinder has reference scales for the most common refrigerants. The desired scale is rotated into position next to the viewing tube to read the cylinder liquid level. (Robinair Mfg. Corp.)

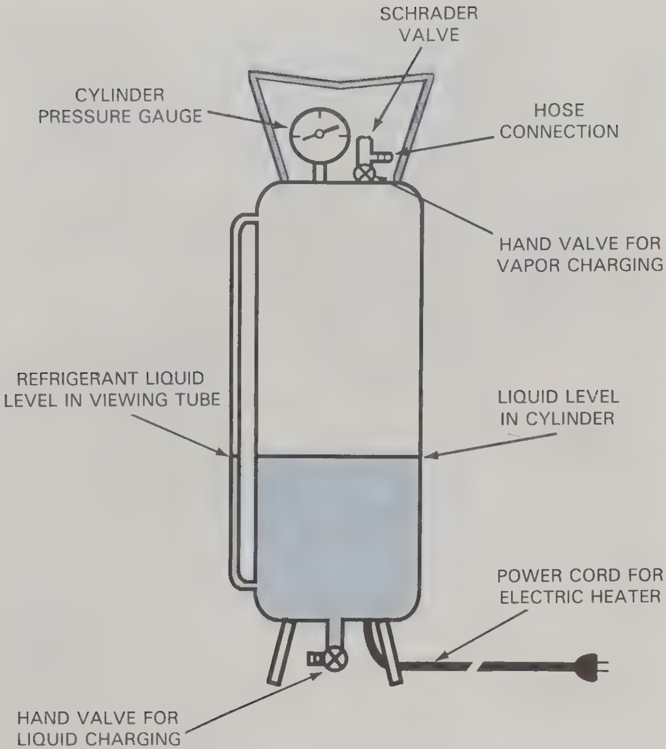


Fig. 13-31. Graduated charging cylinders have valves at the top and bottom to permit either vapor charging or liquid charging. A built-in electric heater is used to increase cylinder pressure when necessary.

level in the graduated cylinder, as shown by the viewing tube, should be slightly more than needed for the system being charged. The graduated cylinder is connected to the system through a gauge manifold, and charging progress monitored by watching the refrigerant level in the viewing tube. The graduated cylinder method allows very precise charging.

SUMMARY

The importance of knowing how to work safely and efficiently with refrigerants and high-pressure gases cannot be too strongly emphasized. The information contained in this chapter will be vital for properly installing, servicing, and troubleshooting refrigeration systems. The chapter explains many servicing and troubleshooting procedures, as well as describing leak detection methods. Charging methods for both vapor and liquid refrigerant were described in detail.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Leak detection using the __________ method is not reliable.
2. List three acceptable methods of leak detection.
3. Name two inert gases commonly used to pressurize systems for leak detection.
4. Why is oxygen never used to pressurize a system?
5. Leak-testing should be done with pressures between __________ psig and __________ psig.
6. The halide torch will detect a leak as small as one ounce per __________.
7. An electronic leak detector will detect a leak as small as one ounce in __________ years.
8. Name two expendable refrigerants.
9. Why are refrigerant cylinders filled to only 85 percent of capacity?
10. __________ cylinders should never be refilled.
11. Temperature charts for three refrigerants are shown on manifold gauge faces. Name them.
12. Normally, controlling the temperature of the __________ around a product allows you to control the temperature of the product itself.
13. The evaporator removes heat from the __________, which (in turn) removes heat from the __________.
14. In a refrigeration system, evaporator temperature should be about __________°F colder than the entering air.
15. Boiling refrigerant inside the evaporator is about __________°F colder than the temperature of the evaporator itself.
16. When a refrigeration system is turned off, is there a temperature difference between the air and the evaporator?
17. In an air conditioning system, what is the temperature difference between the refrigerant and "air off" (the cooled air)?
18. When a refrigeration system (such as one used for a walk-in cooler) is operation, what is the evaporator temperature when the "air on" temperature is 36°F? What is the refrigerant temperature?
19. The purpose of the condensing unit is to remove __________ from the refrigerant vapor so that it will change state back to a __________.
20. High-side pressure depends on the temperature of the __________ air passing through the condenser.
21. How is proper head pressure determined for an air-cooled condenser?
22. On a water-cooled condenser, head pressure should correspond to a temperature that is __________°F to __________°F higher than the temperature of the water leaving the condenser.
23. List five causes of high head pressure.
24. On an air-cooled system that uses R-502 as a refrigerant, what is the head pressure at an ambient air temperature of 80°F?
25. On an air-cooled system that uses R-12 as a refrigerant, what is the head pressure at an ambient air temperature of 60°F?

Chapter 14

WORKING WITH REFRIGERANT CONTROLS

After studying this chapter, you will be able to:
- *Identify, install, and adjust automatic expansion valves.*
- *Identify, install, and service capillary tubes.*
- *Identify, install, and adjust thermostatic expansion valves.*
- *Select and install proper sizes of refrigerant orifices.*
- *Identify and describe the operation of multiplexed evaporators.*

NEW WORDS

automatic expansion valve (AEV)	metering orifice
balanced port valve	modulates
bleedover	multiplexing
boiling point	orifice
capillary tube	overcharge
cross-charged	overload
diaphragm	pressure drop
equalizing	refrigerant control
externally equalized	refrigerant distributor
flash gas	restrict
floodback	sensing bulb
hermetic	starve
hunt and surge	thermostatic expansion valve (TEV)
internally equalized	undercharge

REFRIGERANT CONTROLS

A ***refrigerant control*** is the device that controls the amount of liquid refrigerant entering the evaporator. Since *all* liquid must boil off (vaporize, or change state to a gas) inside the evaporator, the refrigerant control has the task of metering into the evaporator the precise amount of liquid refrigerant that will match the evaporator's boiling capacity. If not enough liquid is metered in, the evaporator will ***starve***; if too much is metered in, ***floodback*** (liquid in the suction line) will result.

Operation of the refrigerant control must be automatic, so that the right amount of refrigerant is supplied to the evaporator. If the evaporator starves because too little liquid is supplied, poor cooling will result from reduced system capacity. Also, pressures will be low, because the compressor will be able to remove gas from the evaporator at a rate faster than the valve is feeding liquid in. Floodback, when too much liquid is being fed into the evaporator for the amount of heat available to evaporate it, can cause damage. The excess liquid in the suction line can be drawn into the compressor and severely damage it.

The refrigerant control acts as the division point between the high-pressure and low-pressure sides of the system. Subcooled liquid at high pressure enters the valve, then exits as a low-pressure saturated mixture of liquid and gas. This ***pressure drop*** across the valve is necessary for proper system operation.

Every evaporator *must* have a refrigerant control; systems with multiple evaporators must have a refrigerant control for each evaporator. Once refrigerant controls are installed and properly adjusted, they are very reliable and virtually trouble-free. Four types of refrigerant controls are discussed in this chapter. They are:

- Automatic expansion valve (abbreviated as AEV or AXV).
- Capillary tube.

- Metering orifice.
- Thermostatic expansion valve (abbreviated TEV or TXV).

AUTOMATIC EXPANSION VALVE

The *automatic expansion valve (AEV)* is a *pressure-type* control that is installed in the liquid line at the evaporator inlet. See Fig. 14-1. Most AEVs are installed with flare connections and are clearly marked to reflect refrigerant flow (**in** and **out**). The highly accurate valve will maintain a constant pressure in the evaporator at any time while the system is running.

Since the AEV is designed to control pressure at its outlet, it will thus respond to and control the pressure inside the evaporator. When evaporator pressure drops below the selected level (by as little as 1 psig), the valve opens wider, admitting more liquid to the evaporator. If pressure increases above the desired level, the valve closes slightly to reduce the amount of liquid entering the evaporator. The AEV continually adjusts (***modulates***) refrigerant flow in this way to maintain constant evaporator pressure.

When the compressor is off (not operating), the AEV is closed as a result of high evaporator pressure. It will remain closed until the compressor cycles back on and reduces evaporator pressure to the valve's setting.

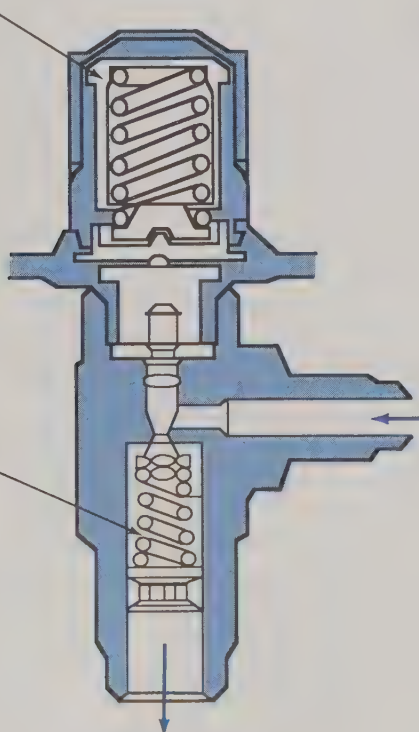


Fig. 14-1. A cutaway view of automatic expansion valve operation. The adjustable opening spring in the top part of the valve forces the rod and ball assembly downward to open the valve as needed. The closing spring moves the ball and rod assembly upward to close the valve.

The desired pressure is set by turning an adjustment screw on top of the valve. This screw, protected by a metal cap, permits adjustment over a wide range of pressures. The technician must know the correct pressure setting, according to the boiling point of the refrigerant inside the evaporator. Adjustment is done by installing the gauge manifold to obtain a low-side pressure reading at the suction service valve. The automatic expansion valve is then adjusted until the proper pressure is registered on the compound gauge of the gauge manifold.

Determining evaporator pressure

The evaporator pressure is determined by the desired temperature of the *product being cooled*. Since the AEV is a constant pressure valve, the evaporator pressure (and thus its temperature) will remain constant. When an AEV is used as the refrigerant control, there is no temperature difference between the evaporator and the refrigerant.

For heat to flow, a temperature difference must exist. When the product temperature is lowered enough to match the evaporator temperature, heat flow stops. As shown in Fig. 14-2, product temperature cannot drop below the evaporator temperature, because no temperature difference exists. In the same way, when the system is turned off, the temperature of the evaporator will match that of the ambient air, and no heat will flow.

The temperature-limiting feature of systems equipped with an AEV is very desirable when cooling liquids such as milk and water. The evaporator is submerged in the liquid and the AEV pressure is set to keep the evaporator temperature just above the freezing point of that liquid. Since heat flow ceases when there is no temperature difference, the liquid temperature can never drop below the evaporator temperature, and thus cannot freeze.

This is illustrated in the milk cooling tank shown in Fig. 14-3. The wall-type evaporator inside the tank is in direct contact with the milk, allowing excellent heat transfer by conduction. The system uses R-12 for a refrigerant, so the AEV is set to maintain a pressure of 31 psig. At this pressure, R-12 would produce an evaporator temperature of 33°F (0.5°C), one degree above the freezing point of milk. The milk stays cold, but cannot freeze.

How the AEV works

The automatic expansion valve functions as a spray nozzle, breaking up the liquid into fine drops as it enters the evaporator. This makes it easier for the refrigerant to *vaporize* or change to a gas. As the gas is drawn into the compressor, pressure inside the evaporator is decreased. The AEV maintains a constant pressure level in the evaporator by metering in enough liquid to balance the vapor drawn out by the compressor. When the compressor cycles off, pressure in the evaporator rises and the AEV closes. It will remain closed until the compressor cycles back on again and lowers pressure in the evaporator.

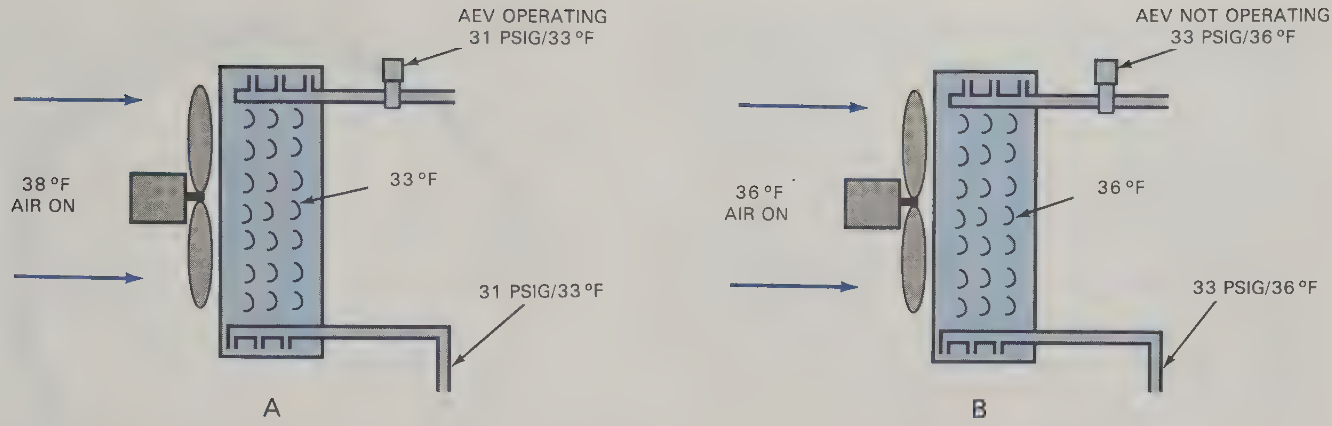


Fig. 14-2. Temperature difference. A–When system is running, the air temperature will drop to match (but never go below) the evaporator temperature. Once temperatures are the same, heat flow stops, so the air temperature remains constant. B–When system is not running, heat will flow from warmer ambient air to evaporator, until the temperatures are the same. When temperatures are the same, heat flow ceases.

Working forces in the AEV are:

- The range adjustment spring pressing downward on the ***diaphragm*** or bellows. This tends to open the valve.
- The closing spring exerting an upward pressure on the push rod and ball assembly, tending to close the valve.
- Pressure on the diaphragm from the evaporator outlet, which tends to close the valve.

Once set by the technician, spring pressure on the adjustment screw remains constant. As a result, the evaporator pressure determines how much the valve opens or closes. A rise in evaporator pressure will overcome spring pressure and force the valve toward a closed position. A drop in evaporator pressure will allow the spring pressure to open the valve wider. This means that the AEV responds to very slight pressure fluctuations, automatically modulating (partially opening or closing) to maintain a constant evaporator pressure.

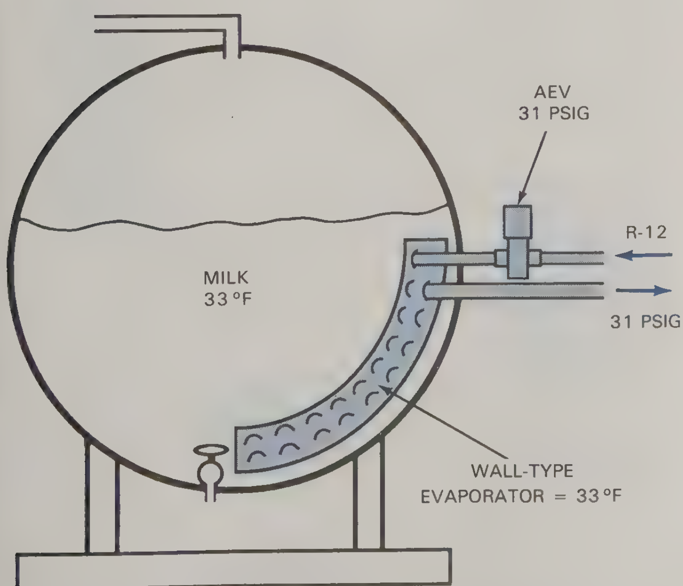


Fig. 14-3. Temperature-limiting feature of AEV systems allows liquids to be kept just above freezing. By holding pressure of R-12 in the evaporator at 31 psig, the temperature of the milk will stabilize at 33 °F.

Adjustment procedure

Install a gauge manifold to monitor pressure readings at the suction service valve (evaporator pressure). With the system running, any adjustment of the AEV setting is immediately reflected on the compound gauge.

AEV setting adjustments are performed by removing the metal cap of the valve and turning the adjustment screw in or out. Turning the screw in (clockwise) increases the spring pressure on the diaphragm. More liquid will enter the evaporator because a higher evaporator pressure will be needed to overcome the AEV spring pressure. Increasing the amount of refrigerant in the evaporator will cause the evaporator pressure to rise. Turning the adjustment screw out (counterclockwise) will have the opposite effect. It will reduce spring pressure on the diaphragm, allowing it to open the valve more easily. This reduces the amount of liquid refrigerant entering the evaporator, and thus lowers the evaporator pressure.

Controlling product temperature

A thermostat within the area of the product being cooled controls operation of the AEV system. When product temperature has been lowered to the selected ("cut-out") point, the thermostat will turn off the system's compressor. With the compressor turned off, pressure in the evaporator rises, closing the AEV.

During the "off" portion of the compressor cycle, the product temperature will slowly rise. The evaporator temperature will slowly rise, as well. Once product temperature rises to the thermostat's cut-in point (typically 5°F above the cut-out point) the compressor will be turned on again.

The AEV will not open immediately, however. It will remain closed until the compressor reduces evaporator

pressure to the valve setting. Adjustments to the AEV can be made only while the system is running, since that is the only way a constant pressure can be maintained.

Selecting an AEV

The technician should select an automatic expansion valve that has a capacity equal to the condensing unit of the system. For example, a system with a one-ton condensing unit should have a one-ton valve. Using too small a valve would "starve" the evaporator; a valve that is too large would ***hunt and surge*** (fluctuate from fully open to fully closed) at start-up.

AEV disadvantages

Increased heat load on the evaporator of an AEV-equipped system causes the evaporator pressure to rise, which in turn causes the AEV to close or "choke down." This means that the evaporator is starved under peak load conditions. This increases the time needed to bring the product temperature down to the desired level. The AEV is best applied to situations that involve a fairly stable heat load, such as ice-making machines.

To control product temperature, the AEV system requires a thermostat. Since low-side pressure is constant on an AEV system, pressure-type motor controls cannot be used.

Systems using the AEV were once popular, but are no longer common. They have largely been replaced by capillary tube or thermostatic expansion valve systems. The *operating principle* of the automatic expansion valve remains in wide use, but not as the primary refrigerant control device. Special valves using the AEV principle have different names and uses, and are explained later in this book.

CAPILLARY TUBE REFRIGERANT CONTROL

A ***capillary tube*** is a length of small copper tubing that has a tiny, accurately sized inner diameter (ID, or hole throughout its length). See Fig. 14-4. Capillary tubes are available in various sizes and are used for a number of purposes.

The capillary tube is used in small refrigeration systems as a *refrigerant control device.* The tube length and small hole (ID) are accurately calculated to ***restrict*** liquid refrigerant flow. The capillary tube is used to control the amount of liquid entering the evaporator.

In operation, one end of the capillary tube is connected to the condenser outlet and the other end to the evaporator inlet. Thus, the tubing serves as both the liquid line and a refrigerant control (metering) device. See Fig. 14-5.

Capillary tube selection

The capillary tubing used on a given system must be precisely sized, and is *not* adjustable. There are four

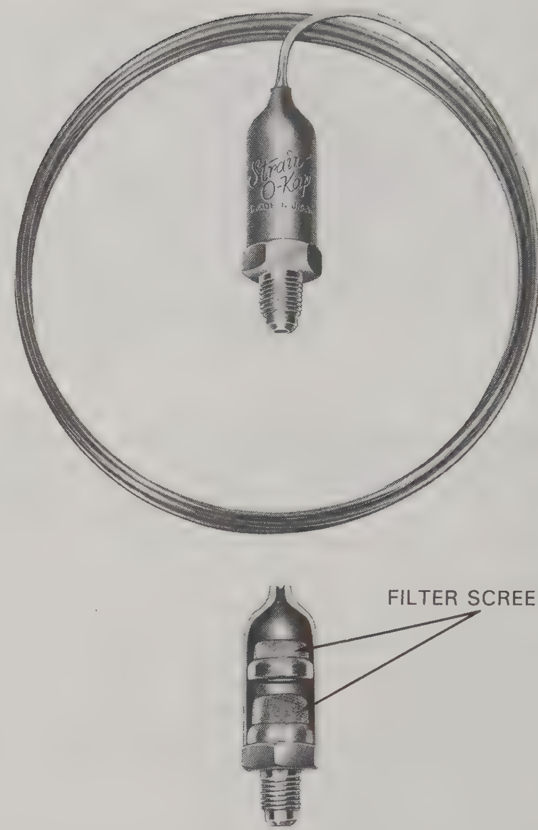


Fig. 14-4. Capillary tubes come in different lengths and have different inside diameters. The tube that is illustrated has a filter at the inlet. The filter, shown in cutaway view at bottom, has fine screens to trap contaminant particles that might clog the very small passage (ID) through the tube. (Watsco)

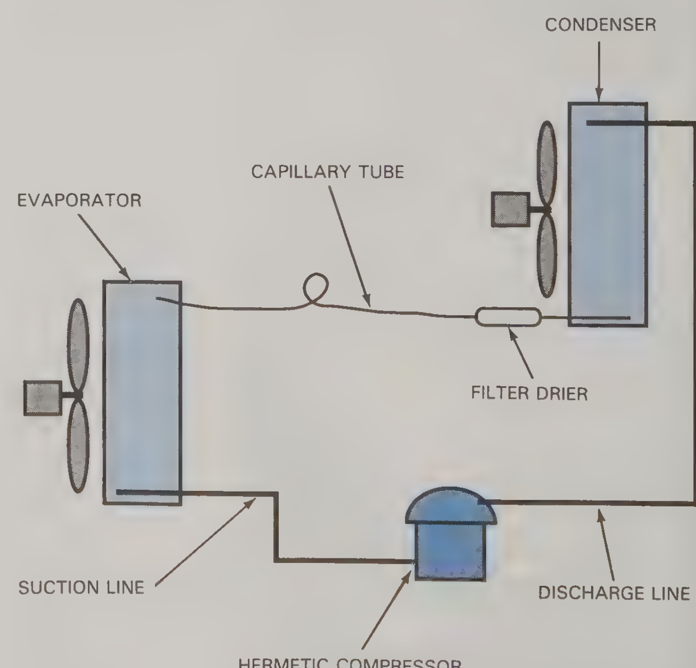


Fig. 14-5. In a capillary tube system, the capillary tube serves as the liquid line, connecting the condenser and evaporator and controlling the flow of refrigerant. Capillary tube systems are often used on domestic and small commercial refrigeration systems.

variables that must be taken into account when selecting capillary tubing:

- Length.
- Inside diameter.
- Refrigerant.
- Tubing temperature.

The capacity of the tube will vary, depending upon the refrigerant used: a capillary tube selected for use with R-22 will have a different capacity if used with R-12 or R-502. Each refrigerant has specific properties that will differ with changing temperatures.

On many domestic refrigerators, the temperature of the capillary tube is controlled by soldering it to the suction line. This arrangement functions as a heat exchanger. The suction line cools the liquid refrigerant inside the capillary, while heat from the capillary tube helps keep frost off the suction line. Some refrigerator manufacturers actually run the capillary tube *inside* the suction line for much of its length.

The amount of liquid entering the evaporator must be balanced with the speed of boiling (rate at which the refrigerant changes to a vapor) and the gas-removing ability of the compressor. This perfect match must occur at the desired boiling point (temperature-pressure relationship). If not enough liquid enters the evaporator to keep up with the compressor's gas-removing ability, the evaporator will "starve." This will result in a lower ***boiling point*** (suction pressure) and lower cooling capacity. Excess liquid entering the evaporator raises the boiling point (pressure) and may permit liquid to enter the suction line. Liquid in the suction line is called "floodback" and could cause severe compressor damage.

Capillary tube systems are designed to maintain the same temperature differences explained in the preceding chapter. In a refrigeration system, this means that the evaporator temperature is 10°F (5.6°C) colder, and the refrigerant temperature is 20°F (11°C), colder than the *air on* temperature. In an air conditioning system, the same temperature differences exist, but are measured from the *air off* temperature.

Selection and installation of the proper size of capillary tube is performed by the system manufacturer. The most common size of capillary tube for use with R-12 has an OD of .114 in. and an ID of .049 in. Field replacement of capillary tubes is not recommended, although it is possible on some systems. Any replacement tube that is installed must be an *exact* duplicate; a replacement compressor installed in a capillary tube system also must be an exact replacement. Every component in such a system is critical. Always follow manufacturers' recommendations.

Capillary tube advantages

The capillary tube is inexpensive and has no moving parts. In addition, it permits a small amount of high-side pressure to bleed over into the low-pressure side during the off cycle. ***Bleedover*** helps reduce the high-side pressure (and thus the starting load) on the compressor. As a result, the system can make use of a less costly compressor that has low starting power.

Bleedover process. Some people refer to the bleedover process as a *balancing* of pressures during the off cycle. This balancing or ***equalizing*** process does *not* mean that the high and low pressures become identical. The pressures do not equalize because the system does not remain off long enough for condenser and evaporator temperatures (and thus pressures) to become equal. As the high-side pressure drops to ambient, the amount of flow through the capillary tube is greatly reduced due to bubbles of vapor. The evaporator is *much* colder than the condenser; the pressure in each will behave as described on the temperature-pressure chart for the refrigerant involved.

When a capillary tube system has shut off, a delay of 2-5 minutes must be allowed before restarting. The delay is needed because the compressor cannot start under normal head pressure (temperatures 30°F-35°F or 17°C-20°C above ambient). An ***overload*** (electrical safety device) will protect the compressor motor until the head pressure is reduced to ambient. *Cycling on the overload* should be avoided–it is a warning that the motor is having problems. Motors and overloads are explained later.

Capillary tube disadvantages

A capillary tube system has a fixed, nonadjustable capacity, so the amount of refrigerant is critical down to one-half ounce. Any overcharging or undercharging of the system will greatly affect operation; the amount of refrigerant in the system becomes *the* determining factor for proper control of system pressures.

Capillary systems are self-contained, which means that the condensing unit is located within the cabinet. These cabinets are normally located inside a building where ambient temperatures are controlled. These controlled ambient temperatures are usually in the vicinity of 70°F (21°C).

Domestic refrigerator condensers are cooled with ambient air, so the head pressure can be predicted by adding 30°F-35°F (17°C-20°C) to the ambient temperature, then consulting a temperature-pressure chart. A system that uses R-12 should have a head pressure that is between 117.2 psig and 126.6 psig (808 kPa and 872.9 kPa):

$$70°F + 30°F = 100°F\ (117.2\ psig)$$
$$70°F + 35°F = 105°F\ (126.6\ psig)$$

The capillary tube for the system was selected to perform at this head pressure, resulting in an evaporator pressure of 1 psig-3 psig (6.9 kPa-20.7 kPa). If the head pressure rises above normal, more refrigerant will be pushed through the capillary tube into the evaporator, resulting in a higher temperature-pressure. Likewise, if the head pressure drops below normal, the flow of

refrigerant is reduced, starving the evaporator. Low-side pressure may fall into a vacuum reading.

An *overcharge* causes *high* head pressure because excess liquid accumulates in the condenser. High head pressure, in turn, causes high suction pressure, since a greater quantity of liquid is pushed through the capillary tube. An *undercharge* will cause *low* head pressure because the condenser is, in effect, "oversized." Since not enough liquid is being pushed through the capillary tube, low head pressure will cause low suction pressure. Gas bubbles in the capillary tube compound the low pressure problem, because the bubbles tend to increase tube resistance.

A further disadvantage of the capillary tube system is the very small passage through the tubing, which can easily be restricted or plugged by dirt, ice, or wax. To help guard against blockage, a filter-drier is always installed at the capillary tube inlet. When opening a capillary tube system for repairs, thorough evacuation is critical for moisture removal. The filter-drier should always be replaced after service.

Working on capillary tube systems

Capillary tube systems are normally ***hermetic*** (sealed) systems, without service valves. In the manufacturing process, "pigtails" or *process tubes* are used to evacuate and charge the system. When charging is complete, the pigtail is pinched closed and cut off. The closed tubing end is then brazed to totally seal the system. For servicing, the technician must install saddle valves or Schrader (core-type) valves. See Fig. 14-6.

A capillary tube or filter-drier that is restricted (partly blocked) will cause low suction pressure and low head pressure. When the suction pressure is low, the load on the compressor is reduced and the condenser becomes "oversized." Subcooled liquid accumulates inside the condenser. Attempting to increase suction line pressure by adding refrigerant is a mistake, since this will cause excessive head pressure and compressor failure.

A restriction will *always* cause a pressure drop, which results in flash gas and a cold surface at the location of the restriction. When a filter-drier's surface is cold (or actually shows frost), it has a restriction and must be replaced.

Another possible cause of low suction and head pressures is an *undercharge*. An undercharge indicates that the system is losing refrigerant through a leak. Adding refrigerant will temporarily alleviate the problem, but will not fix it. The only way to cure a leak is to find and repair it. See Fig. 14-7.

Charging a capillary tube system

A capillary tube system can be charged by slowly adding small quantities of refrigerant vapor to the low-pressure side. This must be done carefully, since capillary tube systems are easily overcharged. Charging is done slowly to permit the system to stabilize after each addition of refrigerant. The evaporator temperature, suction pressure, and discharge pressure will not attain normal status until the system reaches normal operating temperatures.

An overcharge can be recognized by high discharge and suction pressures, and by the presence of frost on the suction line. Correct the overcharge by slowly purging gas from the system, using recovery equipment. The frost line will slowly retract, until it disappears inside the cabinet.

Proper charging cannot be checked until the cabinet temperature is reduced to normal. During charging, the head pressure quickly rises to an above-normal point, while the suction pressure reading is in vacuum. Head pressure must not be allowed to exceed 150 psig (1034 kPa) when using R-12.

Vapor charging occurs faster than the condenser can liquefy incoming gas. Gaseous refrigerant in the capil-

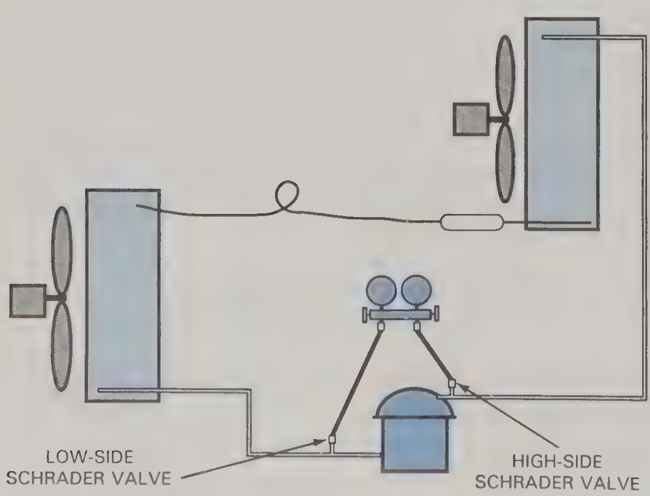


Fig. 14-6. Service valves are not provided on capillary tube systems. Schrader (core-type) valves or saddle valves are installed at the points shown to obtain pressure readings.

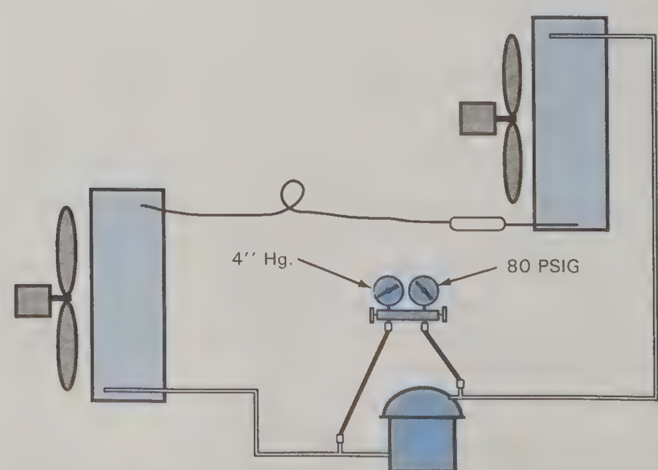


Fig. 14-7. Low pressure on both sides of the compressor indicates either a restriction or a leak. The technician must discover which problem is causing the low pressure, then fix it.

lary tube does not flow like liquid. System pressures should be allowed to stabilize after each addition of refrigerant. Cabinet temperature must be reduced to almost normal before the pressures become normal.

Weighing the charge. A graduated cylinder or electronic scale can be used, as explained in Chapter 13, to quickly and easily charge a capillary tube system. The correct amount of refrigerant is measured and then quickly charged into the system as a vapor. This procedure saves time, but the precise amount of refrigerant being charged into the system must be known. This can usually be found on the data plate of the refrigeration unit. If necessary, check the service manual or contact the manufacturer to obtain the needed information.

METERING ORIFICE

The refrigerant ***metering orifice*** is designed, like the capillary tube, to operate on the principle of *restriction*. While the capillary tube is several feet long, the metering orifice (Fig. 14-8) is very small. The unit has flare connections at both ends, and is installed in the liquid line at the evaporator inlet.

The brass body of the metering device contains a small hole (***orifice***) that is exactly sized to match the equipment. Manufacturer's recommendations must be followed, since the orifice controls the amount of liquid entering the evaporator, and a mismatch could cause problems. The orifice is easily removed for cleaning or replacement.

Operating characteristics of a metering orifice and a capillary tube are identical, but the orifice has the advantage of being accessible and easily replaceable. This accounts for its popularity among manufacturers of residential air conditioning systems and heat pump units.

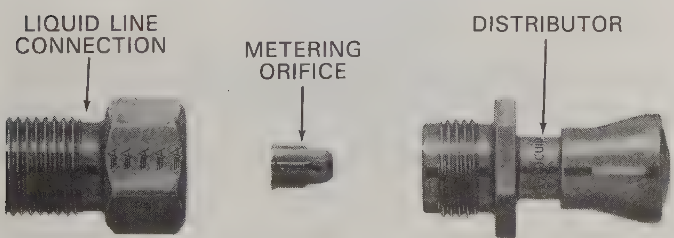


Fig. 14-8. The metering orifice is easily replaceable when necessary. The assembly is located at the evaporator inlet. (Aeroquip Corp.)

THERMOSTATIC EXPANSION VALVE (TEV)

The ***thermostatic expansion valve (TEV)*** is the most common refrigerant control, especially in commercial and industrioal refrigeration and air conditioning applications. The TEV, Fig. 14-9, can be mounted in any position at the evaporator inlet, and is reliable, efficient and virtually troublefree. The operating principle and characteristics of the thermostatic expansion valve are often misunderstood. As a result, the valve is frequently blamed, by mistake, for other system troubles.

Fig. 14-9. Thermostatic expansion valves are made in a wide variety of sizes and various types of connections. (Parker Hannifin)

Controlling superheat

Veteran technicians often refer to the TEV as a "superheat valve," because it maintains constant superheat at the evaporator outlet. This provides maximum efficiency under all types of load conditions. Too much superheat at the evaporator outlet starves the evaporator of liquid and reduces capacity. No superheat at the outlet will permit liquid to enter the suction line.

The amount of superheat at the evaporator outlet will vary according to the speed at which vaporization (boiling) takes place. The speed at which the liquid boils depends on the heat load placed on the evaporator. A high heat load causes the liquid to evaporize rapidly. A low heat load results in slower change of liquid to a gas.

Ideally, the evaporator should be well-supplied with liquid refrigerant under all types of heat load conditions. All liquid refrigerant entering the evaporator *must* be converted to a superheated gas before leaving the evaporator.

How the TEV works

The thermostatic expansion valve is designed to maintain a precise superheat at the evaporator outlet. This provides proper flooding of the evaporator with liquid refrigerant under all load conditions. The valve controls superheat by metering varying amounts of liquid into the evaporator. High superheat at the evaporator outlet causes the valve to open, and low superheat permits the valve to close.

As shown in Fig. 14-10, the valve can be mounted in any position at the evaporator inlet, but the ***sensing bulb*** must be located on the suction line at the evaporator outlet.

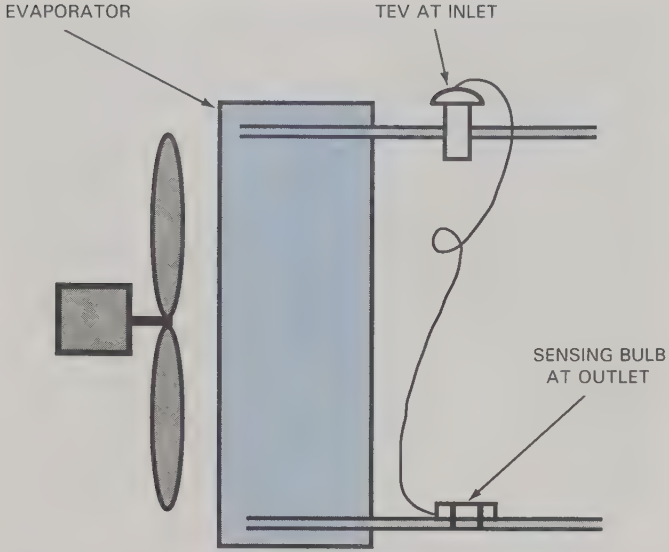


Fig. 14-10. The TEV is mounted at the evaporator inlet, where it can control the flow of liquid refrigerant. The sensing bulb is mounted at the evaporator outlet to monitor changes in superheat.

Superheat at the sensing bulb's location controls the amount of liquid flowing through the valve at the evaporator inlet. The desired amount of superheat (typically 10°F or 5.6°C) is set with an adjustable control on the valve body. The valve opens and closes slightly (modulates) in response to superheat changes. If, for example, the sensing bulb detects 11°F (6°C) of superheat at the evaporator outlet, the valve will open enough to meter more liquid into the evaporator. If the sensing bulb registers 9°F (5°C) of superheat, the valve will close slightly to decrease liquid flow.

The advantage of the valve's modulating action is a properly flooded evaporator at all times, despite changing heat load conditions.

The TEV operates by moving the valve stem (pin) away from the valve seat. As shown in Fig. 14-11, valve stem movement is controlled by four different pressure exerted on working parts. These are:

- Sensing bulb pressure (opens valve).
- Evaporator pressure (closes valve).
- Spring pressure (closes valve).
- High-side pressure (opens valve).

Sensing bulb pressure

The sensing bulb contains a special charge of refrigerant that is extremely sensitive to changes in temperature. As suction line temperature changes, bulb pressure increases or decreases accordingly. For example, a rise in temperature would cause an increase in bulb pressure, which is transferred by means of a capillary tube to the diaphragm of the valve. The diaphragm is pressed downward, acting on push rods. The push rods exert a downward force on the pin carrier, moving the pin out of the seat to open the valve. See Fig. 14-12.

Sensing bulb charges. To provide accurate superheat control for different applications, different types of charges are used in the sensing bulb. In most cases, the bulb is charged with the same refrigerant used in the system. Different operating characteristics are obtained by varying the sensing bulb volume, and thus, the amount of charge. Each valve is designed and charged for a particular application–a valve designed for low pressure cannot be used for high-pressure applications. Sufficient refrigerant is charged into the bulb to ensure that it contains some liquid under all temperature conditions.

Valves designed for use in low-temperature conditions are usually ***cross-charged***. This means that the bulb is charged with a refrigerant different from the one used in the system. The refrigerant used in the bulb is more sensitive to low temperatures.

Valves designed for high-temperature applications have sensing bulbs that are charged with very little liquid. This provides a *pressure-limiting* feature: when all the liquid has vaporized, a further increase in temperature will produce almost no additional bulb pressure. This limits the amount of pressure exerted upon the valve diaphragm. Such valves are normally used in air-conditioning applications.

Sensing bulb mounting. Proper mounting of the sensing bulb is essential for good valve control. As shown in Fig. 14-13, the bulb is clamped to the suction line at the evaporator outlet. It should be located on a horizontal section of the line, upstream from any trap, and should make good thermal contact along its entire

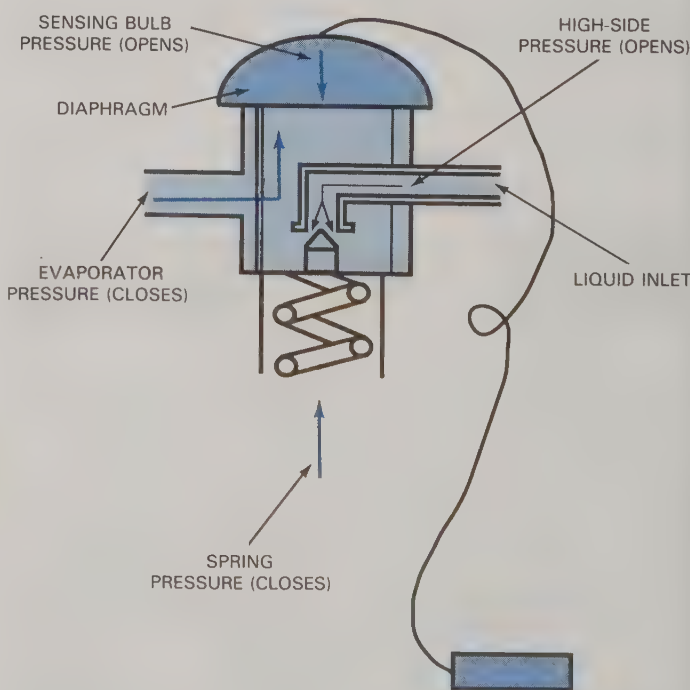


Fig. 14-11. The action of four pressures on the TEV while a system is operating. Pressures tend to either open or close the valve by moving the stem (pin) into or out of its seat.

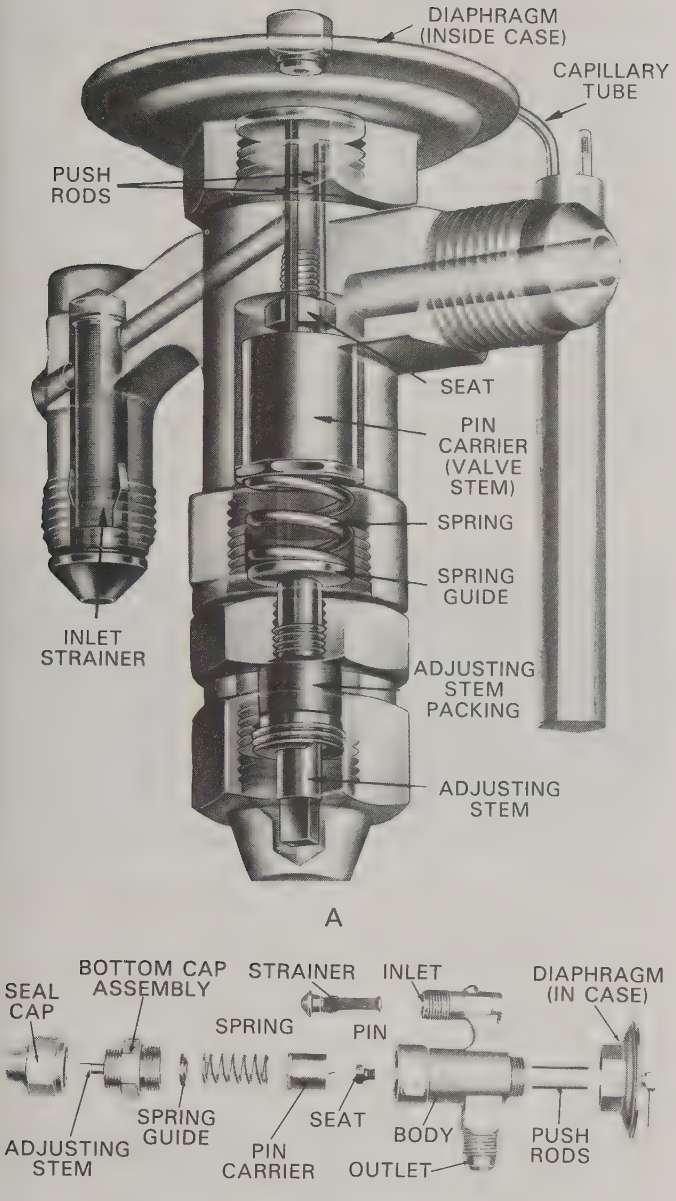


Fig. 14-12. Thermostatic expansion valve. A–Cutaway view of a typical TEV. Varying pressures on the diaphragm and spring modulate operation of the valve. B–Exploded view showing relationships between parts. (Sporlan Valve Co.)

length with the suction line. The bulb is normally secured to the suction line with two copper straps.

On suction lines that are 7/8" (22 mm) or smaller in diameter, the bulb can be mounted on the top or either side of the line. The bottom should be avoided, since any oil flow in the line will be along the bottom, which could prevent the bulb from sensing temperatures correctly. On suction lines larger that 7/8" (22 mm), the sensor should be mounted at the 4 o'clock or 8 o'clock position for most accurate temperature readings.

Evaporator pressure

Evaporator pressure acts on the bottom of the valve diaphragm, providing an upward movement that tends to close the valve (See Fig. 14-11). An increase in evaporator pressure causes the valve to close until the compressor causes a reduction in evaporator pressure.

Slight changes in either evaporator pressure or bulb pressure cause the diaphragm to move up or down by small amounts, causing corresponding changes in the size of the valve opening (modulation) and thus, the flow of liquid refrigerant.

Internally equalized valve. The ***internally equalized*** valve is one in which a special passage built into the valve body transfers evaporator pressure to the underside of the diaphragm. This type of valve is used when there is a pressure drop of less than 2 psig through the evaporator. See Fig. 14-14.

Evaporator pressure drop. The length of tubing making up the evaporator, return bends in the tubing, and the vacuum (sucking) action of the compressor combine to develop a *pressure drop* through the evaporator. As a result, pressure at the evaporator inlet is higher than pressure at the outlet. A large evaporator may have a pressure drop of 6 psig or more. For proper operation of the TEV, correct evaporator pressure on the underside of the diaphragm is essential. Evaporators that have a pressure drop greater than 2 psig must use a TEV that is externally equalized.

Externally equalized valve. An ***externally equalized*** valve is like the internally equalized type, but evaporator

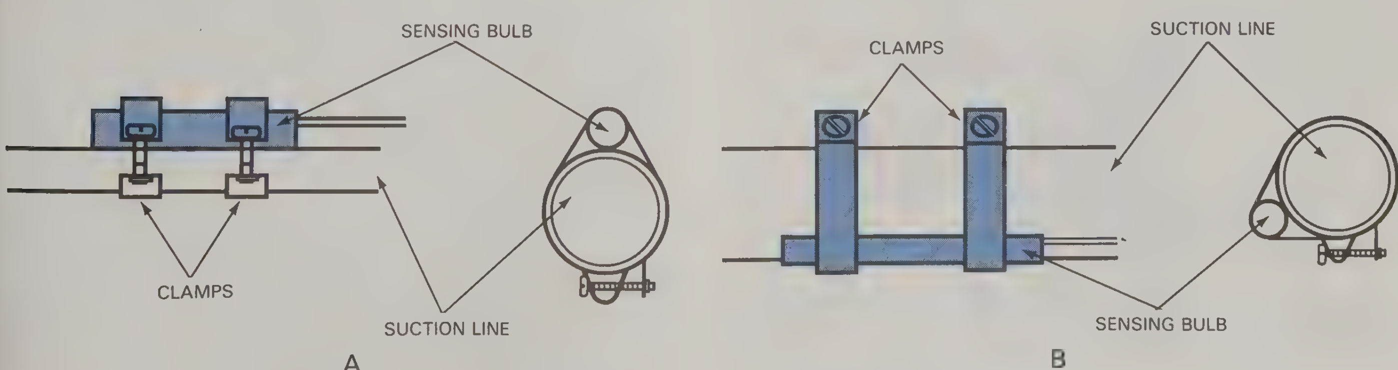


Fig. 14-13. Proper sensing bulb location. A–On suction lines 7/8'' (22 mm) or smaller, bulb should be clamped to the top or side of the line. Avoid bottom-mounting. B–On lines larger than 7/8'' (22 mm), mount the bulb at the 4 o'clock or 8 o'clock position.

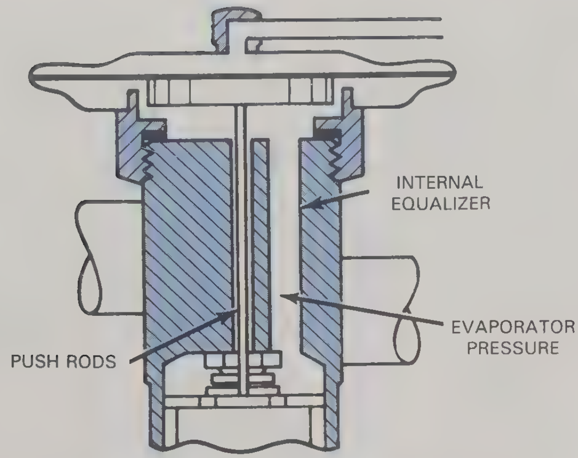


Fig. 14-14. Internally equalized valve. Special passage transfers evaporator pressure to underside of the diaphragm. (Sporlan Valve Co.)

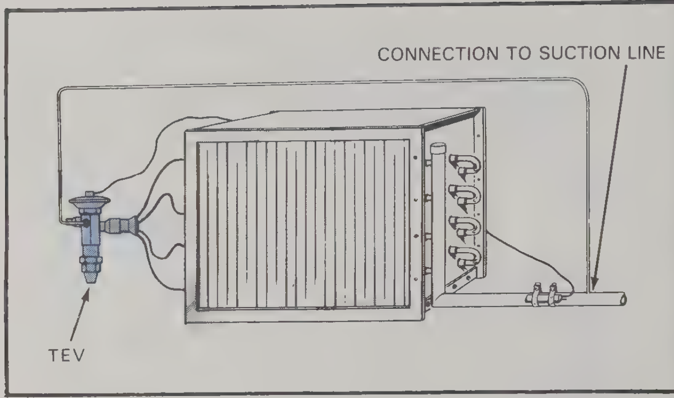


Fig. 14-16. The tubing from an externally equalized TEV is connected to the suction line at a point immediately downstream of the sensing bulb. (Sporlan Valve Co.)

REFRIGERANT	EVAPORATING TEMPERATURE Degrees Fahrenheit				
	40	20	0	-20	-40
	PRESSURE DROP (PSIG)				
R-12 & R-500	2	1.5	1	0.75	0.5
R-22	3	2	1.5	1.0	0.75
R-502	3	2.5	1.75	1.25	1.0

Fig. 14-17. Pressure drop for various refrigerants at different evaporating temperatures. If the pressure drop across the evaporator exceeds these values, a TEV that is externally equalized must be used.

pressure on the underside of the diaphragm is supplied from the evaporator *outlet,* rather than the *inlet*. As shown in Fig. 14-15, a separate passageway to the diaphragm is connected to a 1/4″ male flare fitting on the valve body. Tubing connected to this fitting is run to a point just downstream of the sensing bulb and inserted into the suction line, Fig. 14-16. This transfers the correct evaporator pressure to the valve diaphragm.

An externally equalized TEV must *always* be connected to the suction line. It should never be *capped,* or the valve may flood, starve, or operate erratically. An externally equalized valve may be used with an evaporator that has very little pressure drop. When the pressure drop exceeds the values shown in Fig. 14-17, an externally equalized TEV *must* be used.

SPRING PRESSURE

The valve pin is mounted on a metal *pin carrier* that rides on top of a spring. Two push rods extend from the

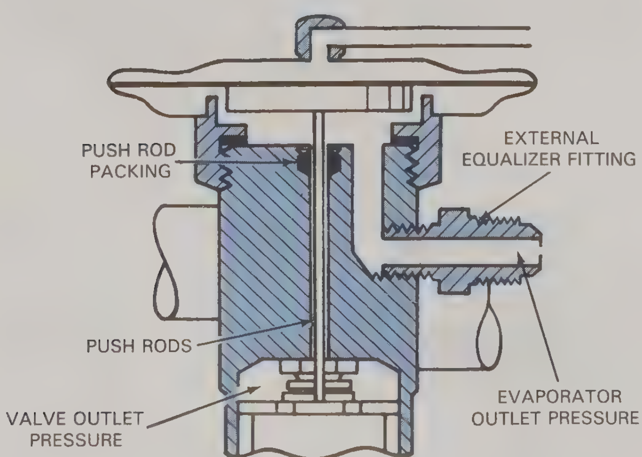


Fig. 14-15. Externally equalized valve. The evaporator pressure is read from a point beyond the outlet, through tubing connected to a flare fitting.

bottom side of the diaphragm to the top of the pin carrier. Upward pressure from the spring creates a closing force, pressing the pin into the valve seat. This force is also exerted on the push rods, which transmit it to the underside of the diaphragm.

Pressure on *top* of the diaphragm (exerted by expansion of refrigerant in the sensing bulb) opposes the pressure on the bottom of the diaphragm resulting from a combination of spring pressure and evaporator pressure. To open the valve, the bulb pressure must be greater than the combined evaporator and spring pressures.

Liquid refrigerant boiling to a vapor at the evaporator outlet will cool the sensing bulb, reducing bulb pressure. Temperatures above saturation (*superheat*) will warm the sensing bulb and increase bulb pressure. The amount of superheat required to open the valve is determined by the closing force exerted by the spring. When the spring pressure is increased, higher bulb pressure is needed to overcome the spring pressure. More superheat is needed to warm the bulb and increase bulb pressure. Decreased spring pressure has the opposite effect: less superheat is needed.

Spring pressure is changed by turning the valve stem. Turning the stem clockwise will increase pressure; counterclockwise rotation will decrease pressure.

HIGH-SIDE PRESSURE

High-pressure liquid refrigerant coming into the TEV tends to open the valve by pushing the pin away from the valve seat. This opening force can be offset by spring pressure. However, spring pressure is fixed and wide changes can occur in head pressure due to changing ambient conditions at the condenser. Severe head pressure changes can result in an imbalance among the valve's operating forces. Preventing wide changes in head pressure will assure more uniform operation of the TEV.

All thermostatic expansion valves are designed to operate at a certain *minimum* head pressure. For example, a valve for use with R-12 requires a minimum head pressure of 100 psig (689.5 kPa). Valves for use with R-22 require 200 psig (1379 kPa); those designed for R-502 need a minimum of 180 psig (1241 kPa). The TEV cannot operate properly when head pressures drop below these minimums. Various methods used to control head pressures are discussed later in this book.

One way of dealing with varying head pressure is to install a ***balanced port valve***. Construction of this valve distributes head pressure between the valve pin and the push rods. By equalizing opening and closing forces, this valve design compensates for a wide range of head pressure changes.

TEV SUPERHEAT ADJUSTMENT

Basically, a TEV operates like any other valve: turning the stem in (clockwise) *closes* it; turning it counterclockwise opens it. Closing and opening the valve permits differing amounts of liquid refrigerant to flow into the evaporator. While the valve stem physically changes the opening of the valve, it actually is–in operating terms–a *superheat* adjustment.

Normal superheat settings

Normally, the TEV superheat setting is 10 degrees. High superheat settings will reduce evaporator capacity, since more evaporator surface is needed to produce the superheat. *Some* superheat is needed, however, for proper operation of the valve. In air conditioning applications, the superheat setting can be as high as 15°F (8°C) before there is a noticeable loss of evaporator capacity. Many low-temperature systems that use R-502 for a refrigerant require 5°F to 6°F (2.8°C to 3.3°C) of superheat. This lower superheat setting provides maximum capacity from the evaporator, and makes use of the colder suction line vapor to cool the compressor.

If you have questions about the correct superheat setting for a particular system, consult the manufacturer of that equipment. Recommendations from a manufacturer are normally the result of extensive laboratory testing.

When a valve is first installed, superheat adjustment is often necessary. Once properly installed and adjusted for superheat control, however, the TEV is virtually trouble-free.

Some thermostatic expansion valves are nonadjustable, and are factory set for a specific superheat value determined by the manufacturer. If symptoms indicate that a superheat adjustment is needed, carefully check for other system causes of incorrect superheat.

Measuring a TEV superheat setting

How well a TEV is performing is easily determined by measuring superheat at the sensing bulb location. For accurate temperature and pressure readings, the system must be running and must be in a stabilized condition. Measurement is made as follows:

1. Install the gauge manifold on the compressor service valves and make a pressure reading.
2. Obtain an accurate reading of the suction line temperature at the sensing bulb location.
3. Convert the pressure reading to a temperature value, using the temperature-pressure chart for the refrigerant in the system. This is the *saturation* temperature.
4. Subtract the saturation temperature from the actual temperature read at the sensing bulb. The difference is *superheat*.

Allowing for pressure drop. A pressure reading at the suction service valve will be lower than a pressure reading at the evaporator outlet. This is called *suction line pressure drop*, and will be limited to about 2 psig (13.7 kPa) if proper line sizing and good piping practice have been followed when installing the system. For an accurate superheat reading, this pressure drop must be taken into account. This is done by adding 2 psig to the pressure at the suction service valve *before* converting that pressure to a temperature reading.

Fig. 14-18 illustrates how superheat is measured on a system using R-22. As shown, the temperature of the suction line at the sensing bulb is 52°F (11°C). Pressure at the suction service valve is 66 psig (455 kPa). To allow for pressure drop, 2 psig (13.7 kPa) is added for a total of 68 psig (468.8 psig).

Converting 68 psig to temperature reveals a saturation temperature of 40°F (4°C). Subtracting this from the actual temperature of 52°F (11°C) yields the superheat: 12°F (7°C).

Changing the superheat setting. To change the superheat setting of the TEV, the adjusting stem is turned clockwise (to increase superheat) or counterclockwise (to reduce superheat). When the stem is turned in (clockwise), the valve opening is reduced in size, permitting less liquid to enter the evaporator. When the stem is turned out (counterclockwise) the valve opens wider, so more liquid can flow into the evaporator.

Adjustment should be made gradually to avoid overshooting the desired setting. Make no more than one turn of the valve stem at a time, then allow enough time

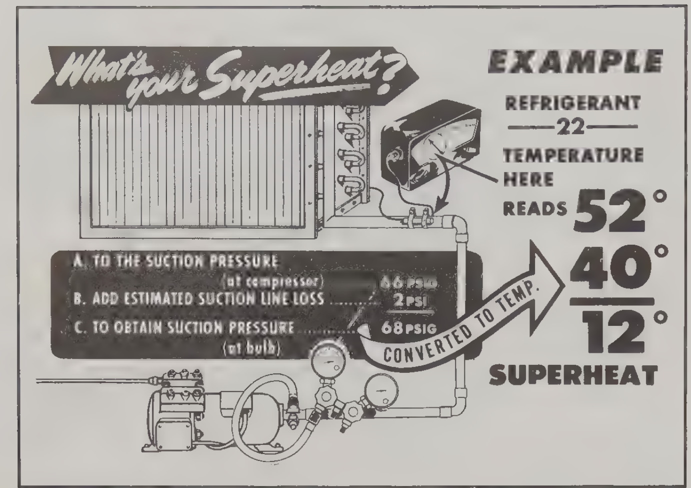


Fig. 14-18. Allowing for suction line pressure drop when calculating superheat. (Sporlan Valve Co.)

for the system to stabilize (as much as 30 minutes may be needed) before making any further change.

Evaporator temperature

The TEV does not control evaporator temperature or low-side pressure–it maintains *a constant superheat,* regardless of temperature or pressure. It is sized to match the capacity of the evaporator and compressor.

In operation, there is a difference of approximately 20°F (11°C) between the temperature of the product being cooled and the temperature of the refrigerant. The *evaporator* temperature falls midway between the two: 10°F (5.6°C) colder than the product, but the same amount warmer than the refrigerant.

As the system runs, the product temperature is reduced. This, in turn, reduces the heat load on the evaporator. As the heat load is reduced, less liquid flows into the evaporator.

Since the compressor removes vapor from the evaporator at a fixed rate, less liquid flowing into the evaporator results in lower pressure inside the evaporator. This lower pressure means a lower boiling point for the refrigerant, and thus, a colder evaporator. Therefore, the 20°F (11°C) from product to refrigerant is maintained. The superheat setting will be maintained as well, regardless of evaporator temperature.

When product temperature reaches the desired level, the system will be turned off by a thermostat or a low-pressure control. When the system is turned off, the compressor stops running, and cannot remove vapor from the evaporator. Evaporator pressure rises quickly, as the refrigerant remaining inside the evaporator warms up to match the product temperature. This increase in evaporator pressure will be transferred to the bottom of the diaphragm in the TEV, closing the valve. The valve will remain closed during the "off" portion of the cycle, because the evaporator (closing) pressure is sufficient to overcome the bulb (opening) pressure.

Flash gas

The term used to describe what results when liquid refrigerant passes through the TEV orifice is ***flash gas***. The sudden pressure drop (from high to low) causes some of the liquid to instantly boil (flash) into a gaseous state, or vapor. See Fig. 14-19. The heat needed to cause this boiling action is drawn from the remaining liquid, which is cooled to the lower pressure. The remaining liquid then boils at the proper evaporator saturation temperature.

The amount of flash gas is determined by the amount of pressure drop across the valve. This "loss" of liquid refrigerant is necessary as the refrigerant moves from a higher pressure, higher temperature part of the system to a lower pressure, lower temperature section (the evaporator). The expansion valve is the division point between the high-pressure and low-pressure sides of the system.

The amount of liquid that "flashes" into a gas can be reduced by subcooling the liquid before it reaches the valve orifice. Subcooling the liquid will make the system more efficient. A heat exchanger can be installed to subcool the liquid, but many systems accomplish it by simply having long, uninsulated liquid lines between the condenser and the TEV.

REFRIGERANT DISTRIBUTOR

On larger evaporators with multiple circuits, a ***refrigerant distributor*** is used. The distributor, Fig. 14-20, receives refrigerant directly from the thermostatic expansion valve and divides it equally among all evaporator circuits.

In any refrigerant system, the refrigerant control is a division point where high pressure is changed to low

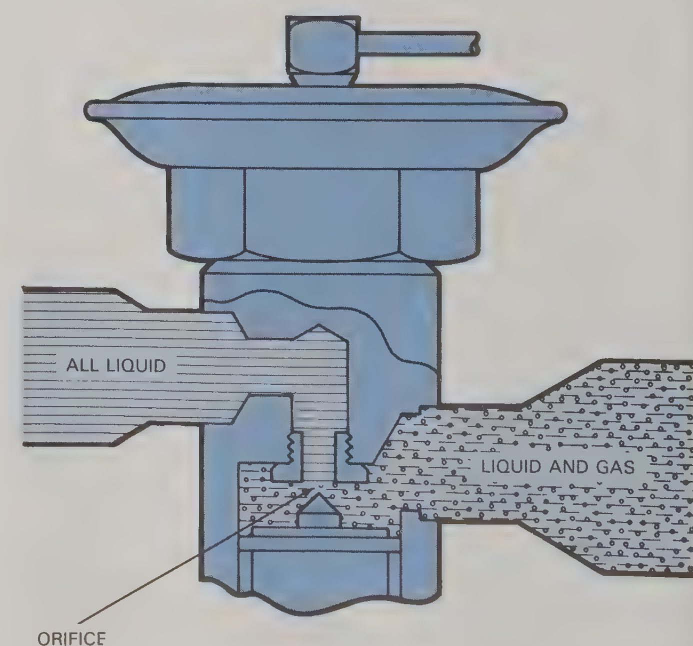


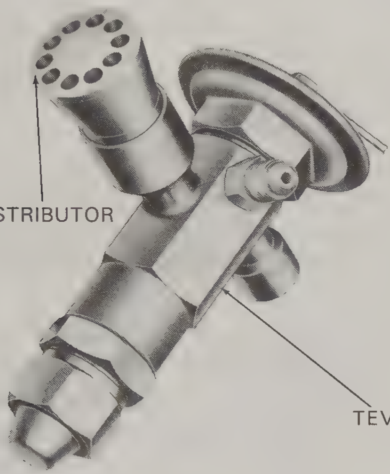
Fig. 14-19. A portion of the liquid refrigerant will "flash" into a gaseous state as a result of the pressure drop when it passes through the TEV orifice. (Sporlan Valve Co.)

(evaporator) pressure. On systems that do not include a distributor, all pressure drop is taken across the valve. When a distributor is used, some pressure drop occurs *across the distributor*. Pressure drops across the distributor for common refrigerants are shown in table form in Fig. 4-21. Any system using a distributor *must* use a TEV that is externally equalized.

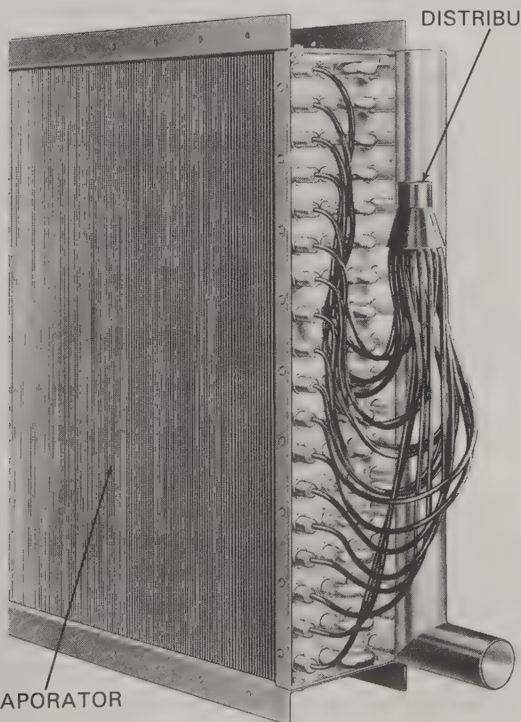
When brazing a distributor to a TEV, be careful to direct the torch flame away from the valve body, as shown in Fig. 14-22. To prevent excessive heat from damaging the valve diaphragm while brazing, wrap the valve body in a wet cloth.

REFRIGERANT	AVERAGE PRESSURE DROP ACROSS DISTRIBUTOR
R-12	25 PSIG
R-22	35 PSIG
R-500	25 PSIG
R-502	35 PSIG

Fig. 14-21. Pressure drop across the distributor for the most common refrigerants.



A



B

Fig. 14-20. Distributors are used in larger systems with multiple evaporator circuits. A–Distributor mounted directly to a TEV. B–Distributor mounted in a vertical downflow position to direct refrigerant to 18 different evaporator circuits. (Sporlan Valve Co.)

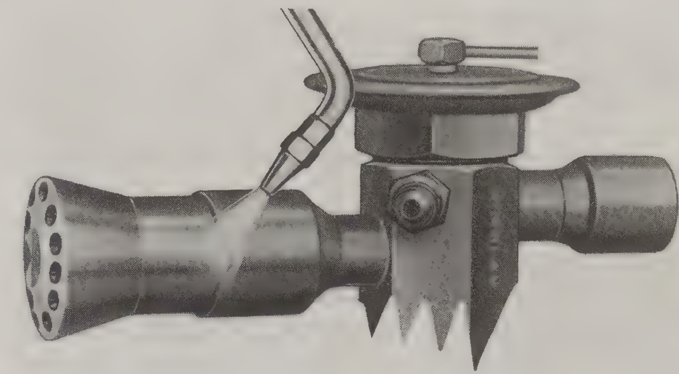


Fig. 14-22. Direct the flame of the brazing torch away from the valve body to prevent heat damage to the diaphragm. Technicians often will wrap the valve body in a wet cloth to help protect it from heat. (Sporlan Valve Co.)

VALVE MOUNTING

The thermostatic expansion valve may be mounted in any position, but should be installed as close to the evaporator inlet as possible. If a distributor is used, it is mounted directly to the outlet of the TEV. Most valves are installed with a flare connection or mechanical flanges, but some make use of brazed connections. See Fig. 14-23.

TEV CAPACITIES

Thermostatic expansion valve capacities are rates in tons of refrigeration. Capacity will vary, based on these factors:

- Orifice size.
- Pressure drop across the valve (liquid line pressure to evaporator pressure)
- Amount of flash gas (liquid temperature vs. evaporator temperature)
- Refrigerant used.

It is vital to use a valve of the correct capacity. If an undersized valve is used, the evaporator will starve despite superheat adjustment. If the valve is oversized, it will hunt and surge (alternately starve, then flood, the evaporator).

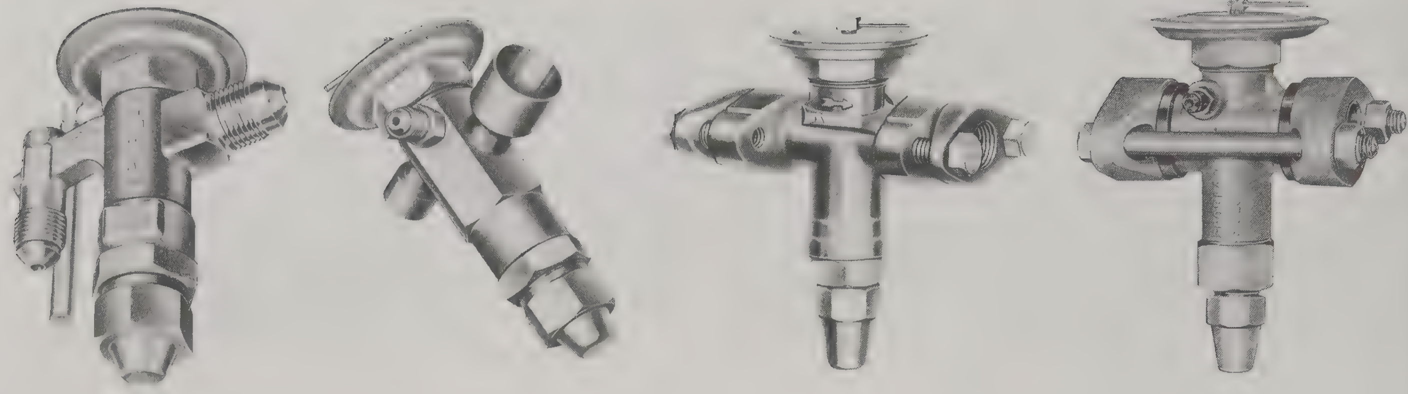


Fig. 14-23. TEV mounting variations. A–Flare connection. B–Brazed connection. C–Pipe thread/mechanical flange connection. D–Brazed/mechanical flange connection. (Sporlan Valve Co.)

Color codes

A major consideration when selecting a TEV is the type of refrigerant used in the system, since expansion valves are not interchangeable among refrigerants. To help identify valves, the tops of the diaphragms are color-coded (the colors, however, are not *always* the same as those used to identify refrigerant cylinders). The TEV codes do, however, provide another method to identify the refrigerant being used in a system. The American Refrigeration Institute (ARI) has established a standard (750-81) for the color coding of thermostatic expansion valves:

Yellow	R-12
Green	R-22
Orange	R-500
Purple	R-502
Blue	Uncommon refrigerants with no designated color

Number codes

Each valve has printed on its body or diaphragm a set of numbers (or letters and numbers) that is the manufacturer's coded information about the valve. These codes are not secret, and information on how to read them is freely available from manufacturers. The code numbers are usually needed when ordering replacement parts.

MULTIPLE EVAPORATOR SYSTEMS

The operating principle of the thermostatic expansion valve makes it possible to connect two or more evaporators to a single compressor. This is called ***multiplexing***. Each of the evaporators operates at the same temperature level, since all are connected to a common liquid line and a common suction line. See Fig. 14-24.

In a multiplexed situation, evaporator capacities are added together to determine compressor size needed. An example of multiplexing is found in supermarkets: a line of four or five frozen food cases might be served by a single compressor located in an equipment room. Each case has its own TEV, evaporator, fans, and other components. Common liquid and suction lines connect the evaporators in the cases.

It is very important, in multiplexed installation,to adjust each TEV for the proper superheat. Adjusting the TEVs individually for proper superheat control provides maximum efficiency from each evaporator and prevents floodback.

MULTIPLEXING ADVANTAGES AND DISADVANTAGES

The major advantage of multiplexing is the elimination of duplicated components, with resulting cost savings. In addition to saving on material costs, multiplexing saves time in installation, cuts energy costs, and saves space.

The only disadvantage of multiplexing is the use of a single compressor. If that compressor burns out or malfunctions in any way, the freezer cases might have to be emptied and the product moved to another freezer until repairs can be made.

SUMMARY

To become a successful technician, you must understand the operating principles of the various refrigerant controls. One or more of these controls is found on every refrigeration system. Each control operates differently to meter the amount of refrigerant entering the evaporator. As a result, service and repair procedures differ for each type of control or system.

The temperature-pressure at which the refrigerant boils (vaporizes) in the evaporator is controlled by the amount of liquid being metered into the evaporator. The flow of liquid into the evaporator must be balanced with the amount of vapor leaving the evaporator through the suction line.

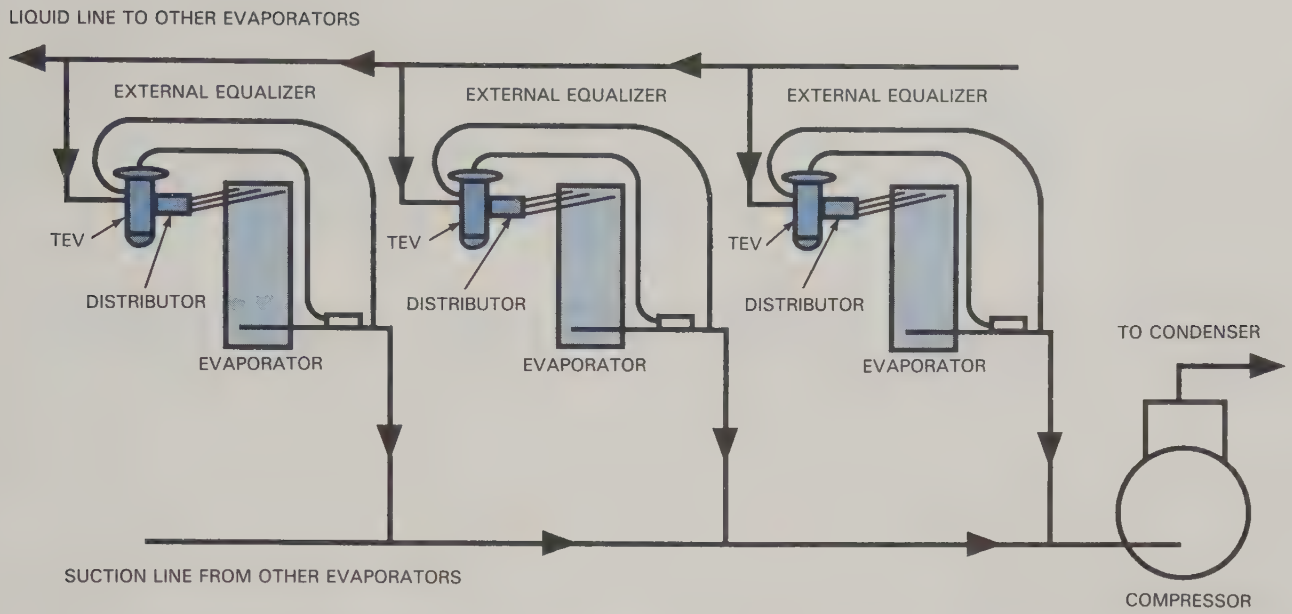
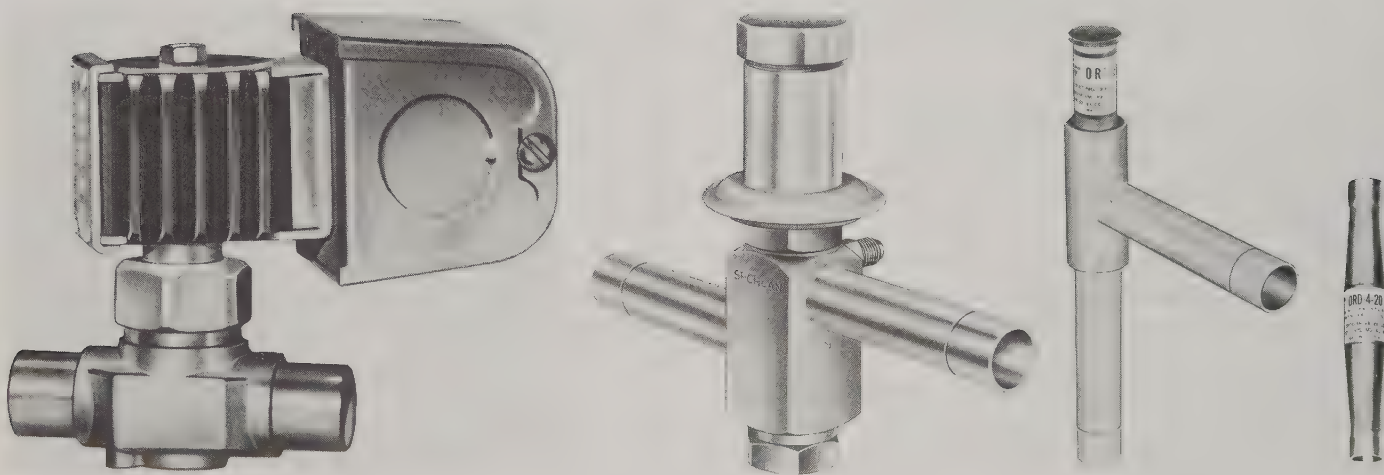


Fig. 14-24. In a multiplexed installation, a number of evaporators are connected to a single compressor, sharing common liquid and suction lines.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What is the purpose of the refrigerant control?
2. Name four common types of refrigerant controls.
3. Refrigerant controls are located at the inlet of the ________.
4. What is the purpose of the automatic expansion valve?
5. Does the AEV open or close on a rise in the evaporator pressure?
6. What are the two forces that operate the AEV?
7. The capillary tube works on the principle of ________.
8. True or false? The four variables of a capillary tube are length, I.D., temperature, and the refrigerant used.
9. Name three advantages of the capillary tube as a refrigerant control.
10. In capillary tube systems, what device controls product temperature?
11. Name two disadvantages of the capillary tube.
12. The refrigerant flow orifice is used in place of the ________.
13. What is the purpose of the TEV?
14. Does low superheat cause the TEV to open or close?
15. Name the four pressures that affect operation of the TEV.
16. Proper mounting of the ________ is essential to correct operation of the TEV.
17. On suction lines less that 7/8″ in diameter, the sensing bulb should not be mounted on the ________ of the tubing.
18. Is the external equalizer line of a TEV connected to the suction line upstream or downstream of the sensing bulb?
19. If you increase the spring pressure on a TEV, will you increase or decrease the superheat?
20. The normal superheat setting is ________°F.



A B C

Special purpose valves, such as those shown here, are frequently used on air conditioning and refrigeration systems. (Sporlan Valve Co.) A–Soleniod valve. B–Hot gas bypass valve. C–Adjustable head pressure valve and differential valve combination.

Chapter 15

SPECIAL-PURPOSE VALVES

After studying this chapter, you will be able to:
- *Identify, install, and properly use hand valves.*
- *Identify and install check valves.*
- *Describe operation of and install solenoid valves.*
- *Install and adjust EPR and CPR valves.*
- *Describe operation of, install, and adjust head pressure control valves.*
- *Install and adjust hot gas bypass valves*

NEW WORDS

capacity control
check valves
clockwise
counterclockwise
crankcase pressure regulator
desuperheating TEV
differential valve
discharge bypass valve
evaporator pressure regulators
hand shut-off valves
head pressure control valve
hot gas bypass valve
humidity
multiplexed evaporators
normally closed (NC)
normally open (NO)
pumpdown cycle
short cycle
solenoid valve
two-temperature system

ACCESSORY FLOW CONTROL VALVES

Many systems include special accessory flow control valves used to increase system efficiency, provide safety features, make repairs easier, or to provide additional system features. These special flow control valves are in addition to regular refrigerant controls, such as the TEV. It is quite common to see one or more special purpose valves on any particular system. Each serves a particular purpose and any malfunction greatly affects operation of other system components. These valves are simple in operation and purpose, but can be misleading to the uninformed. Knowledge of these valves will prevent time-consuming mistakes. This chapter explains these special purpose valves and the function they serve in the system.

HAND SHUT-OFF VALVES

Hand shut-off valves are installed on commercial and industrial systems as a convenience for service technicians. Hand valves make it possible to quickly isolate sections of a system for such tasks as quickly changing a filter-drier. For safety purposes, local codes often specify the installation of hand valves in commercial and industrial refrigeration and air conditioning systems.

Manually operated valves must be sturdy and must be designed to withstand frequent opening and closing without leaking. Pressure drop across the valve must be minimal. Diaphragm-type, globe-type, and ball-type valves are available for such applications. Each may be soldered or flare connected to copper tubing. See Fig. 15-1.

For proper operation, a hand valve must be installed according to the designed direction of flow through the valve body. An arrow on the valve body indicates correct refrigerant flow direction. Diaphragm-type hand valves are used for smaller lines, while ball and globe valves are used for larger lines.

The turning knob (handle) of a *diaphragm valve* is connected directly to the valve stem. *Ball valves* have a metal cap nut over the valve stem. The cap nut must be removed for access to the valve stem. *Globe valves* also have a cap nut over the valve stem, but the cap nut has extension handles for easy turning. This cap nut has a

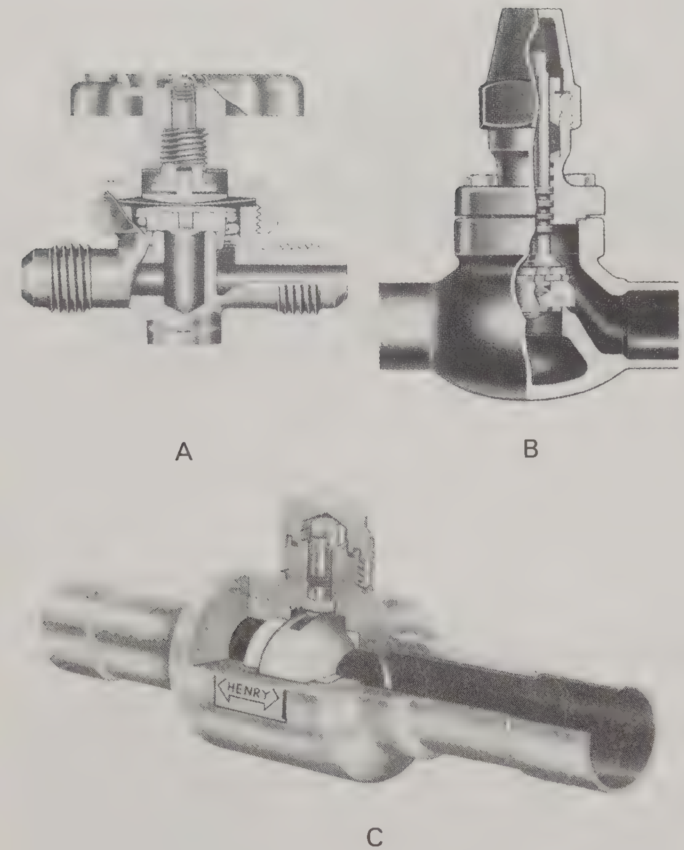


Fig. 15-1. Manually operated (hand) valves. A–Diaphragm-type valve. B–Globe-type valve. C–Ball-type valve (Henry Valve Co.)

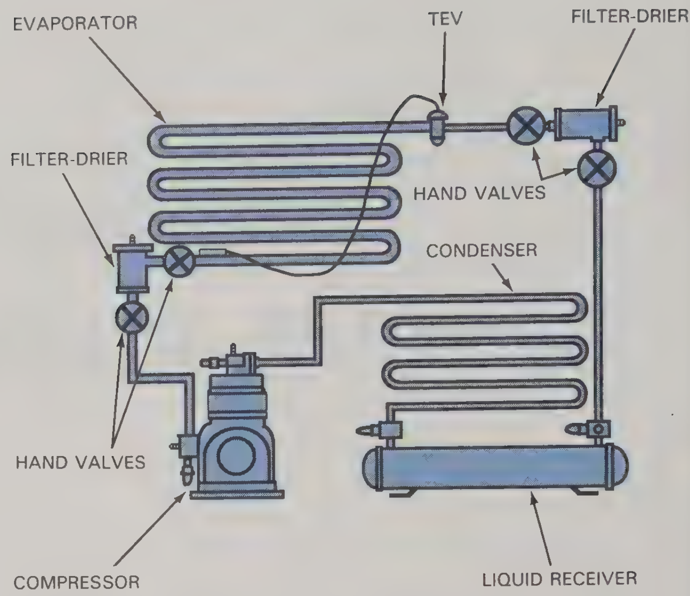


Fig. 15-2. Hand valves can be used to isolate and evacuate portions of the refrigeration system without loss of refrigerant. They are often used to permit easy changing of filter-driers.

recessed opening, so that it can be turned upside-down and used as a wrench to turn the valve stem.

When brazed connections are used, overheating can damage the valve. The valve body should be protected by a wet cloth, and the torch flame directed away from it. Use proper flame tip size to avoid prolonged heating, and to keep melted alloy from flowing into the valve body.

Hand valves can be installed in any line to evacuate and isolate specific sections of the system, as shown in Fig. 15-2. This makes it possible to perform repairs without loss of refrigerant.

CHECK VALVES

Check valves are used in some refrigeration systems to prevent flow of refrigerant in the wrong direction. Proper direction of flow is indicated on the body of these nonadjustable valves. If the liquid or vapor is flowing in the proper direction, the check valve will be open. A change of direction causes the valve to close tight, preventing reverse flow. See Fig. 15-3.

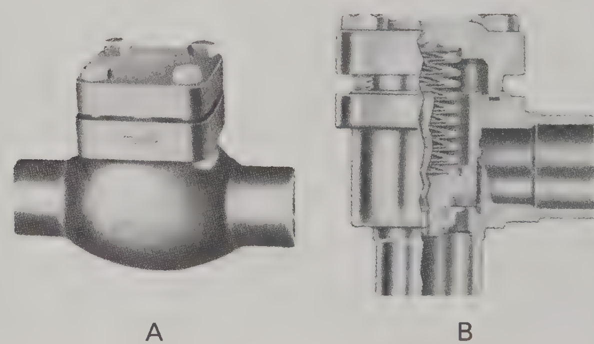


Fig. 15-3. Check valves. A–The arrow on the body of this globe-type check valve shows proper direction for flow. B–This cutaway angle-type check valve shows the spring that holds the seat closed. Flow into the valve from the bottom will be allowed to pass, but backward flow (from the right) will be blocked. (Henry Valve Co.)

EVAPORATOR PRESSURE REGULATING (EPR) VALVE

Evaporator pressure regulators are special valves used to prevent evaporator pressure from falling below a set limit. See Fig. 15-4. EPRs make it possible to connect multiple evaporators with different temperatures to a single compressor.

These valves are installed in the suction line and operate much like an automatic expansion valve. But while the AEV controls pressure at the valve *outlet*, the EPR controls pressure at the valve *inlet*. A TEV is used to assure proper evaporator flooding. The EPR is installed in the suction line to provide a low temperature-pressure limit. This prevents evaporator pressure (and corresponding temperature) from dropping below the EPR setting. This combination of valves thus assures proper flooding of the evaporator and a low pressure limit. The EPR can be installed anywhere in the suction line and still perform properly. See Fig. 15-5.

As noted, the primary function of the EPR is to prevent evaporator pressure from falling below a certain

point. If the evaporator pressure rises above the valve setting, the EPR will open and release the pressure. When the evaporator pressure drops to the valve setting, the EPR will close, preventing further pressure drop. The EPR is a "hold back" type of valve that automatically throttles vapor flow from the evaporator to maintain its setting. The valve modulates very closely to the actual setting, constantly making very slight adjustments to control evaporator pressure.

To adjust an EPR valve, remove the cap and turn the adjustment screw with the proper-size hex wrench (1/4″ or 5/16″). A ***clockwise*** (CW) rotation increases the valve setting; a ***counterclockwise*** (CCW) rotation decreases the setting. To obtain the desired setting, a pressure gauge should be attached to the inlet side of the valve so the effects of any adjustments can be observed. Make small adjustments and allow adequate time between adjustments to allow the system to stabilize at the new setting.

EPRs are normally available in two pressure adjustment ranges: 0-50 psig (0-345 kPa) and 30-100 psig (207-690 kPa). The 0-50 psig range is suitable for most applications. The 30-100 psig range is used for applications involving R-22 and R-502, with evaporating temperatures of 20°F (-7°C) and above. An access port or Schrader valve is provided on the EPR inlet side for connecting a pressure gauge. Inlet pressure readings are necessary when making pressure adjustments. Adjustments to the EPR should be performed *before* checking TEV superheat and making any needed adjustments.

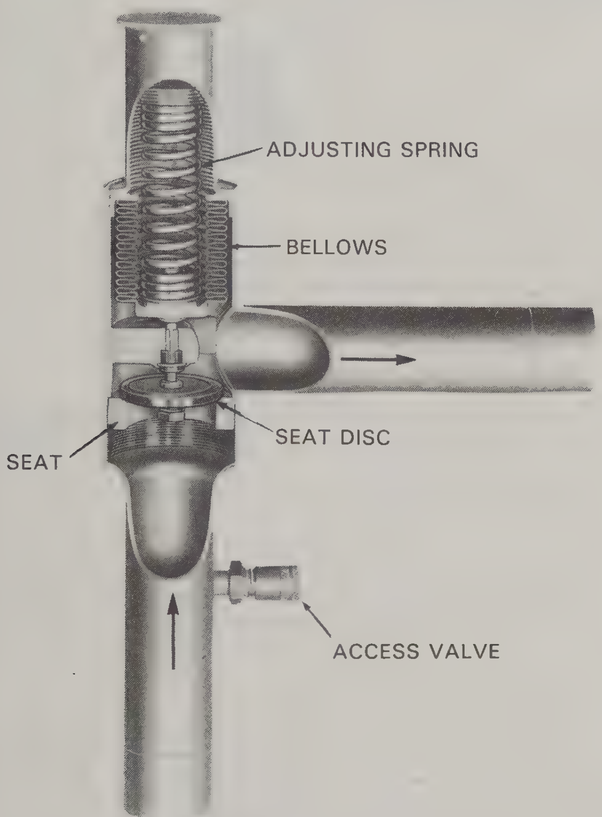


Fig. 15-4. The evaporator pressure regulator valve (EPR) keeps pressure at the evaporator inlet from dropping below a specified limit. This cutaway view shows the major components of a typical EPR. (Sporlan Valve Co.)

Application of EPRs

One application is a single evaporator system, such as a water chiller where the EPR is used to prevent freezing of the water, Fig. 15-6. The valve's pressure adjustment is set to keep the evaporator pressure (and thus, refrigerant temperature) above the freezing point of water. The EPR will prevent evaporator pressure from dropping below this setting.

Another EPR application is the ***two-temperature system.*** This system has two evaporators, operating at different temperatures, but connected to a single compressor. One evaporator, for the walk-in meat cooler, is operating at 32°F (0°C); the other, for the cutting room, is operating at 40°F (4°C). See Fig. 15-7. An EPR

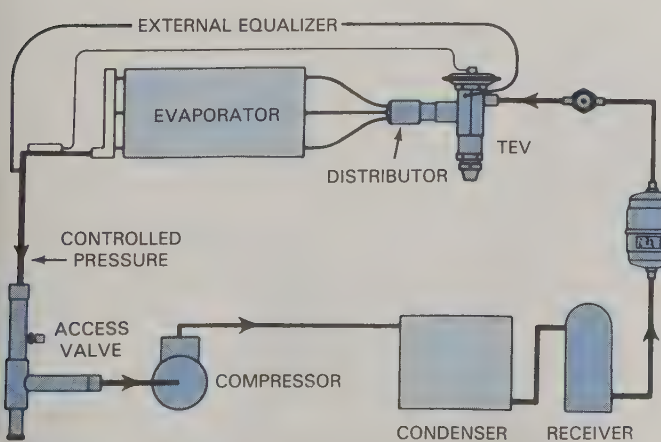


Fig. 15-5. An EPR valve can be installed anywhere in the suction line and still control pressure at the evaporator inlet. (Sporlan Valve Co.)

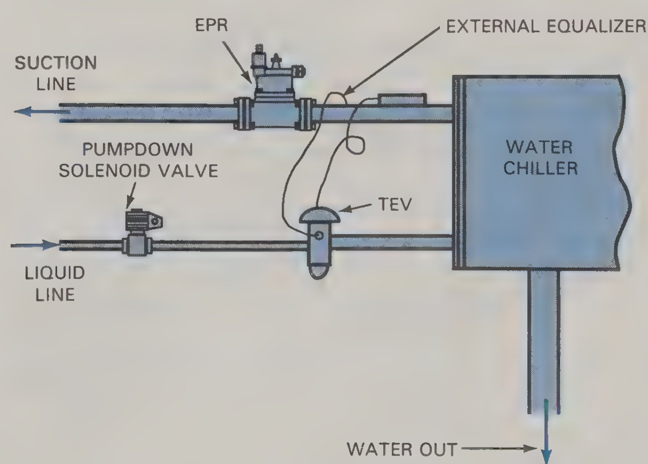


Fig. 15-6. An EPR being used to prevent evaporator freeze-up in a water chiller application. The evaporator temperature is prevented from falling far enough to allow water to freeze.

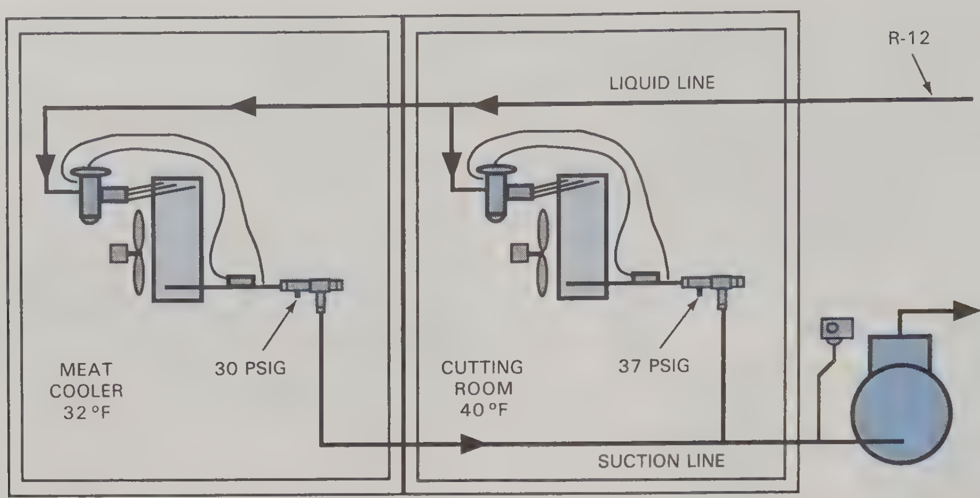


Fig. 15-7. A two-temperature system using two EPR valves. With R-12 as the refrigerant, the meat cooler would have a temperature of 32 °F and a pressure at the access valve of 30 psig. The cutting room would have a temperature of 40 °F and a pressure of 37 psig.

is installed on each evaporator to prevent pressure from dropping too low. This system explains why EPRs are sometimes referred to as "two-temperature valves." EPRs are a necessity when one compressor is connected to multiple evaporators.

An EPR is used when one evaporator operates at low temperature (a freezer) and the other at medium temperature (a cooler). With two evaporators, a freezer EPR is unnecessary. The operating controls (thermostat or pressure control) is set for controlling the *freezer*, and the *cooler* temperature is controlled by an EPR. See Fig. 15-8. With a two-temperature system, the warmer evaporator becomes a "parasite" feeding off the colder system.

Check valves are used on two-temperature applications in which two evaporators operating at different temperatures are connected to one compressor. A check valve is installed in the suction line of the coldest evaporator, as shown in Fig. 15-8. This valve prevents warm suction gas from flowing into the freezer evaporator during the off cycle. The warmer suction gas entering the freezer evaporator would create problems in the colder evaporator, possibly cause the system to ***short cycle*** (turn on and off rapidly).

Multiplexed evaporators

EPRs make it possible to operate multiplexed evaporators at different temperature levels. ***Multiplexed evaporators*** refers to a system in which several evaporators are connected to a single compressor. See Fig. 15-9. Normally, such evaporators would operate at nearly the same temperature. EPRs, however, make it

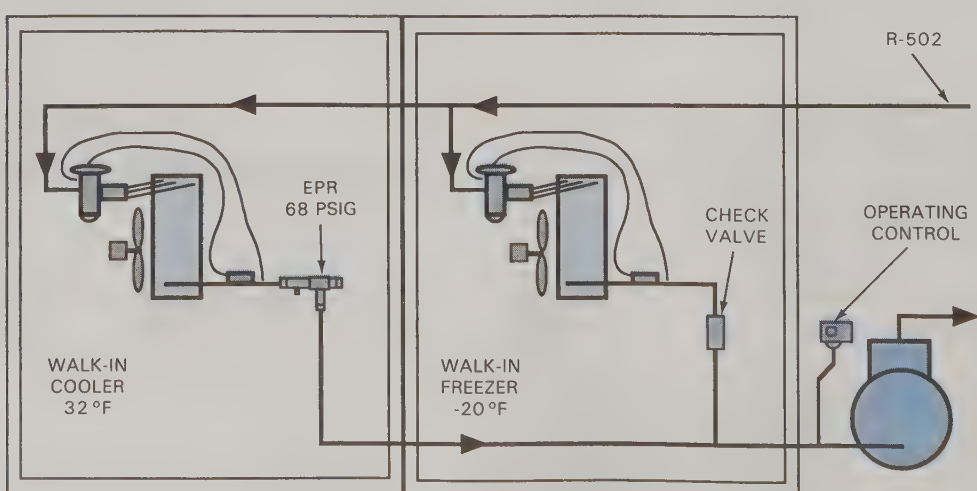


Fig. 15-8. A two-temperature system using one EPR and the system operating control to regulate temperature in two different areas. An EPR keeps the walk-in cooler at 32 °F (a pressure of 68 psig), while the system operating control keeps the freezer at -20 °F. The refrigerant used is R-502.

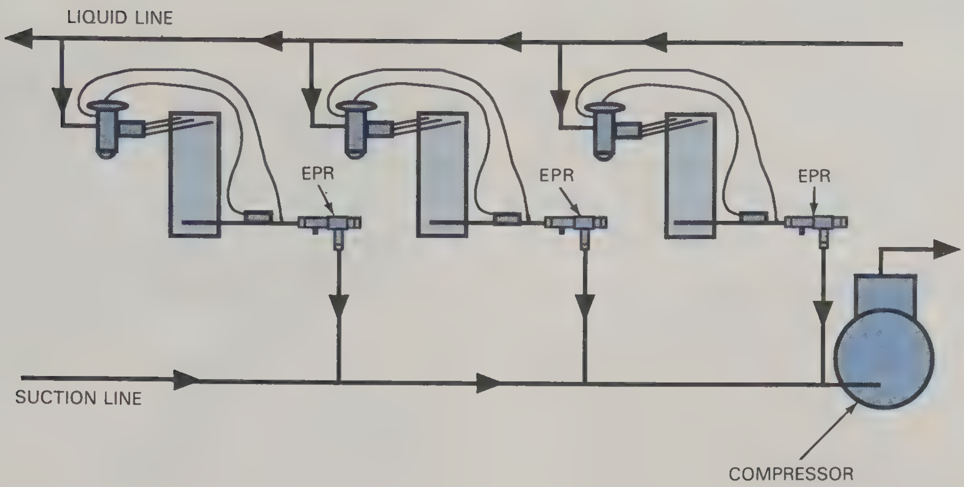


Fig. 15-9. Multiplexed evaporators, each with its own EPR valve to permit individual control of pressure (and thus temperature). Any number of evaporators can be connected to a single compressor and individually controlled in this way.

possible to operate each evaporator at a different temperature level. There is no limit to the number of evaporators that can be connected to a single compressor.

Disadvantages of EPR valves

Using several evaporators means that a large compressor will be needed, with the danger of system failure. Replacing a large compressor is time-consuming and expensive, and considerable loss of product could occur during the downtime.

Provision often must be made to control compressor capacity under reduced load conditions. Under low load conditions, the large compressor reduces suction pressure too rapidly. Short cycling would occur. Compressor cylinder unloaders may be required, or a ***hot gas bypass valve*** may be installed to meter small amounts of hot gas into the suction line during low- load periods. These procedures are explained later.

Multiple compressors

The problems caused by using multiplexed evaporators are easily overcome by using multiplexed *compressors*. Rather than a single 60 hp compressor, three 20 hp units are mounted side-by-side. They are connected to a common suction manifold and a common discharge manifold. See Fig. 15-10.

With multiplexed compressors, if one compressor fails the others keep the system operational until repairs are completed. All compressors will operate under full load conditions, which occurs when most of the EPRs are open. Large systems require large EPRs like the one illustrated in Fig. 15-11.

The load is reduced when the EPRs throttle down, causing a reduction in suction line pressure. When the suction line pressure is reduced to a predetermined point, one of the compressors is turned off. Each compressor

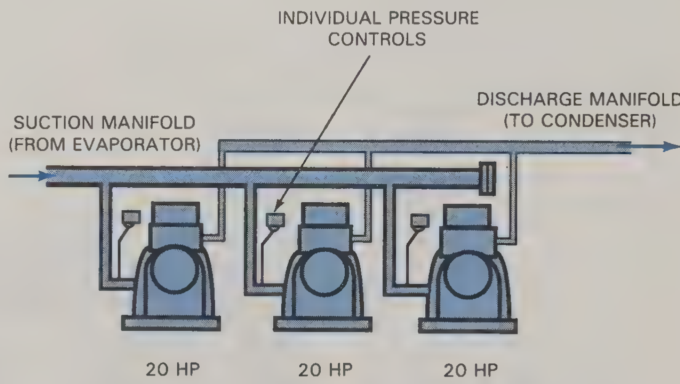


Fig. 15-10. A multiplexed compressor system overcomes problems associated with multiplexed evaporators. Individual pressure controls cycle the compressors on as needed. If a compressor fails, the system will continue to operate with the remaining units.

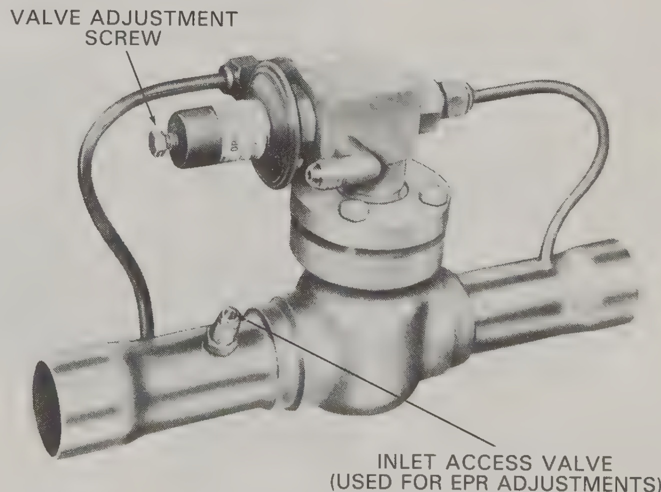


Fig. 15-11. A large evaporator pressure regulating valve, of the type used with large multiple-compressor installations. (Sporlan Valve Co.)

is cycled off in rotation, according to reducing suction line pressure. The individual pressure switches will restart each compressor in response to increasing suction line pressure.

Many supermarkets use the multiplex system having EPRs and multiplexed compressors, such as the one shown in Fig. 15-12. One rack of four compressors will operate on R-502 and control all the low-temperature evaporators, such as frozen food cases, walk-in freezers, and ice cream cases.

Another rack of four compressors will operate on R-12 or R-22 and control all medium-temperature evaporators, such as walk-in coolers and dairy, produce, and fresh meat cases. On four-compressor systems like these, one compressor will operate constantly because the load is never reduced to the point that it can shut off. The other three compressors will cycle on and off due to changing load conditions signaled by pressure changes in the suction manifold.

SOLENOID VALVES

Solenoid valves, Fig. 15-13, are commonly used in refrigeration and air conditioning systems. These valves serve a vital role in the automatic flow control of

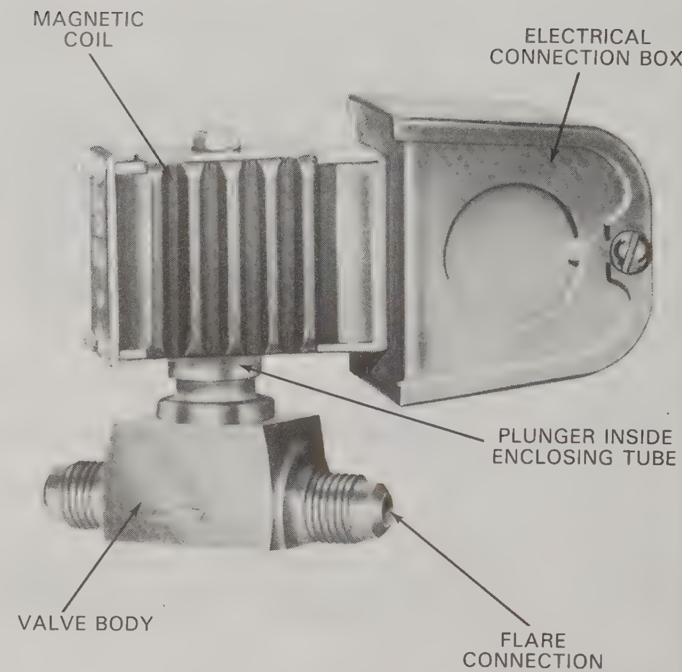


Fig. 15-13. A typical solenoid valve. A magnetically operated plunger opens or closes the valve to regulate the flow of fluid. Valves are supplied with either flare or sweat-type connections. (Sporlan Valve Co.)

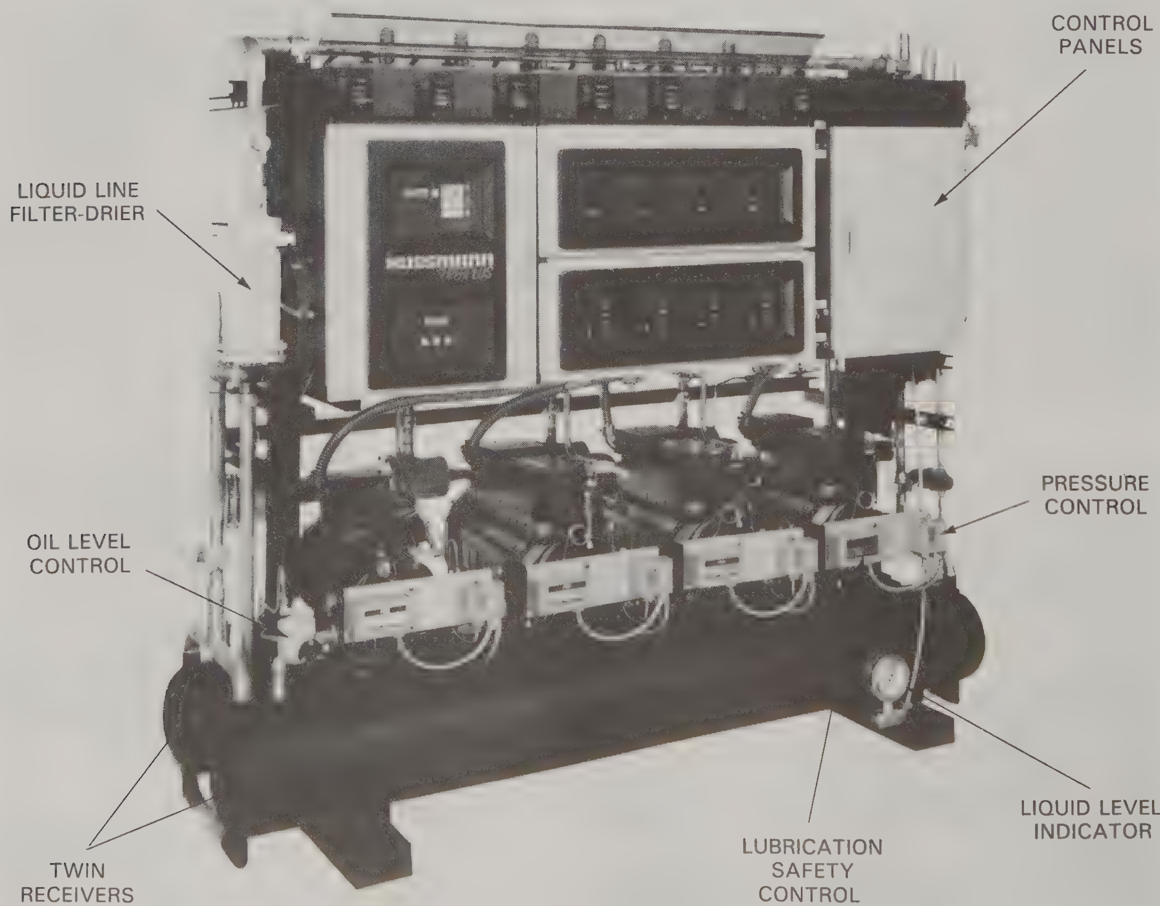


Fig. 15-12. A multiple-compressor system of the type often used to meet the varied refrigeration needs of modern supermarkets. (Hussmann)

refrigerant, water, or other gases and liquids involved in the cooling process.

Solenoid operating principles

A ***solenoid valve*** is an electrically operated valve that is either fully open or fully closed, depending upon whether electricity is on or off. Solenoid valves contain an electromagnet surrounding a plunger connected to a short valve stem. The electromagnet, Fig. 5-14, is a coil of insulated copper wire wrapped around a soft iron core with a round hole through the middle. Electricity flowing through the coil produces magnetism in the iron core. When electrical flow is stopped, magnetism also stops. This magnetic coil is replaceable and is available in different voltages.

The valve body section contains the valve seat, tubing connections, and a free-floating plunger connected to the valve stem, Fig. 15-15. The plunger and valve stem are enclosed in a metal tube extending upward from the valve body. A special lock nut holds the enclosing tube to the valve body for a leaktight seal. The heavy plunger is free to move up and down in the enclosing tube, which fits into the hole in the electromagnet.

When the coil is magnetized by the flow of electricity, an opposing magnetic field is induced in the plunger. The plunger is pulled upward into the center of the magnetic field, Fig. 15-16. Lifting of the plunger opens the valve. When the coil is deenergized, the plunger drops to the closed position. Sometimes, a small spring is located on top of the plunger to assist in closing.

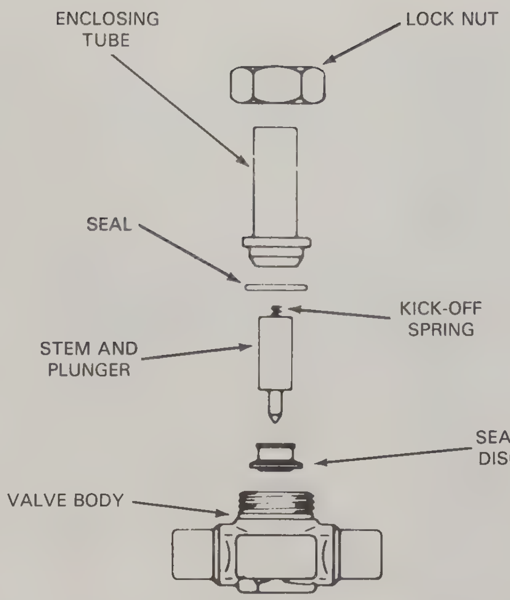


Fig. 15-15. An exploded view of the solenoid valve assembly. The magnetic coil, which surrounds the enclosing tube, has been removed for clarity. (Sporlan Valve Co.)

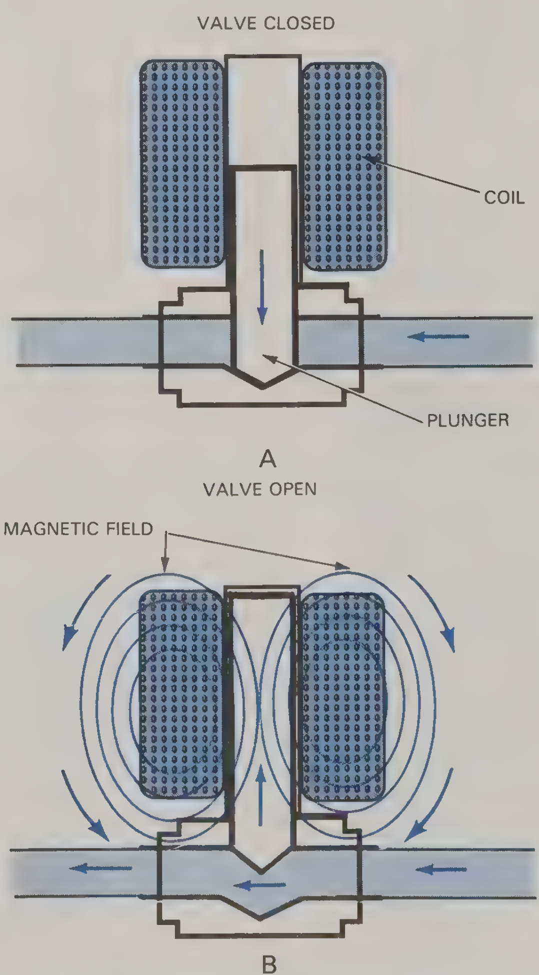


Fig. 15-16. Operation of the solenoid. A–With no electricity flowing to coil, plunger is in ''normally off'' position, blocking flow. The valve is closed. B–Electricity energizes the coil, creating a magnetic field that pulls the plunger up into the enclosing tube. The valve is open.

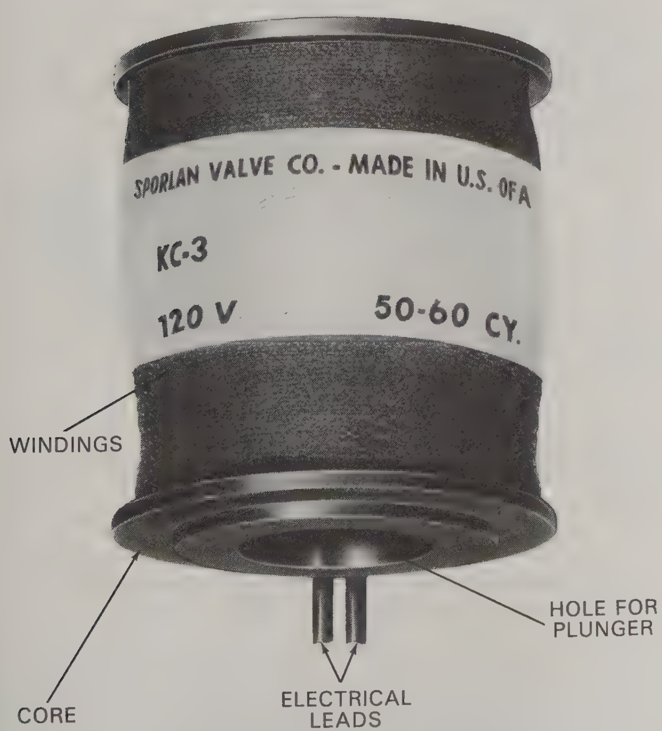


Fig. 15-14. The magnetic coil used in a solenoid has a hole in the middle for the plunger. Coils are replaceable. (Sporlan Valve Co.)

Solenoid installation

For proper plunger operation, a solenoid valve must be mounted in an upright position, or at no more than a 45° angle. Special solenoid valves that use a closing spring, instead of relying on gravity, can be mounted horizontally (sideways). Most solenoid valves are ***normally closed (NC)*** until energized, but valves are available that are ***normally open (NO)*** and close when they are energized. Direction of flow is indicated by an arrow or the word "IN" on the valve body.

Before brazing, solenoid valves should be disassembled to protect internal components from heat damage. Merely removing the coil is not sufficient. Remove all the internal solenoid valve parts illustrated in Fig. 15-17. It is important to avoid overheating the valve body. Brazing should be performed quickly and the flame should be directed away from the body. Avoid excess alloy flowing into the valve.

Solenoid valve and pumpdown cycle

A common example of using solenoid valves is the automatic pumpdown cycle. See Fig. 15-18. A solenoid valve is installed in the liquid line between the sight glass and the TEV. Location can be just before the TEV (evaporator area), or just after the sight glass (condensing unit area).

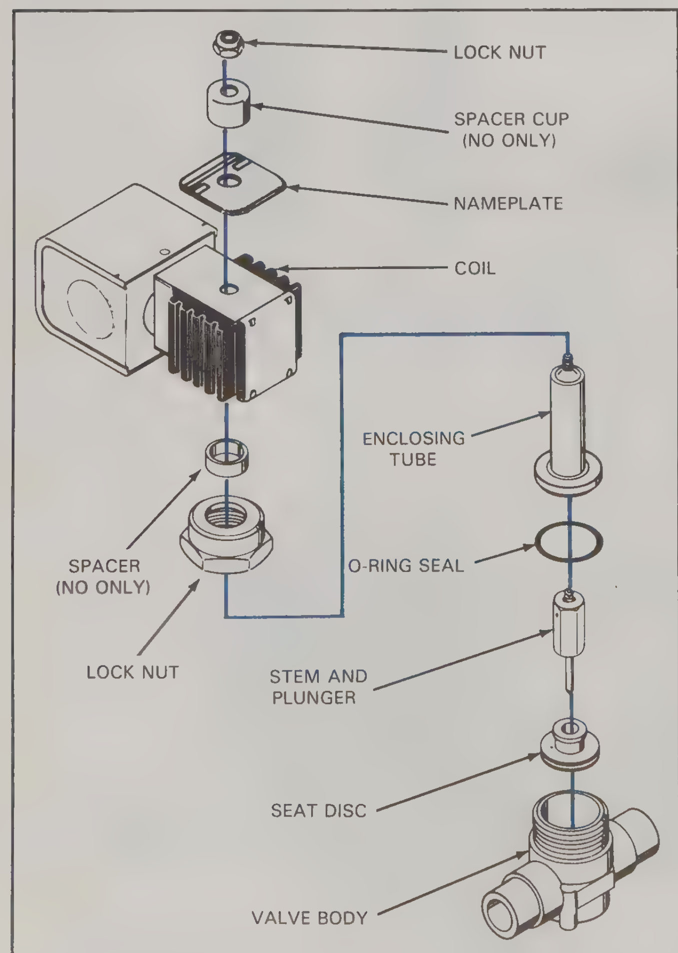


Fig. 15-17. Internal parts of the solenoid, shown in this exploded view, should be removed before brazing. This will protect them from heat damage when the body is brazed to the tubing. (Sporlan Valve Co.)

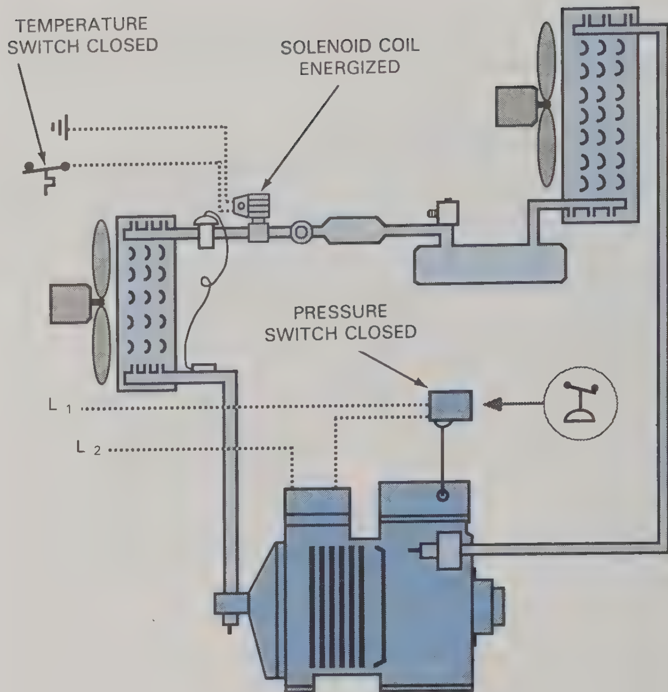


Fig. 15-18. In the "run" cycle, the closed temperature switch energizes the solenoid coil, opening the valve and permitting refrigerant to flow. The closed pressure switch permits the compressor to run.

A temperature control (thermostat) is mounted within the cooled space and electrically connected to the solenoid coil. When temperature within the space rises to the cut-in point on the thermostat, a switch will close and complete an electrical circuit to the solenoid coil. The solenoid coil is energized, opening the valve and allowing refrigerant flow.

The system will continue to operate until the temperature in the space to be cooled is lowered to the cut-out point on the thermostat. At the cut-out point, the switch will open, stopping the flow of electricity to the solenoid coil. The solenoid plunger will drop to the closed position. Refrigerant flow will stop, but the compressor will continue running.

On a ***pumpdown cycle,*** the compressor is controlled by a pressure-sensitive switch that senses suction line pressure. This pressure control is adjusted to stop the compressor just before suction pressure reaches a state of vacuum. The switch also turns the compressor on again when suction pressure rises to the proper setpoint.

Pumpdown run cycle. When the solenoid coil is energized by the thermostat, the valve opens and permits liquid refrigerant flow to the TEV. Refrigerant flowing into the evaporator causes the suction pressure to rise. The pressure-sensitive motor control turns the compressor on. Normal refrigeration continues until product temperature is lowered to the cut-out point on the thermostat.

Pumpdown off cycle. When the thermostat switch opens, electrical flow to the solenoid coil stops and the valve closes. Refrigerant flow to the TEV stops. See Fig. 15-19. The compressor continues to run until the low-side pressure is reduced to the cut-out point on the pressure-sensitive motor control (about 1-2 psig or 7-14 kPa). The compressor should stop before suction pressure reaches a vacuum. This results in all refrigerant being removed from the low-pressure side following each run cycle. Some refrigeration and air conditioning systems *require* a pumpdown cycle like this one to avoid high suction pressure at start-up. Pumpdown also assures good oil return to the compressor and evacuates the evaporator prior to defrost. Heat from electric defrost heaters would create very high suction pressure at start-up.

CRANKCASE PRESSURE REGULATORS

Crankcase pressure regulator (CPR) valves are used to protect the compressor from excessive suction pressure, which most often occurs at start-up. Like the EPR valve, the CPR is a pressure-limiting device. The CPR, however, is constructed to limit *outlet* pressure. See Fig. 15-20.

The CPR is a holdback-type valve. As shown in Fig. 15-21, it is mounted in the suction line very close to the compressor. CPR valves control or *limit* pressure leaving the valve. This protects the compressor from exces-

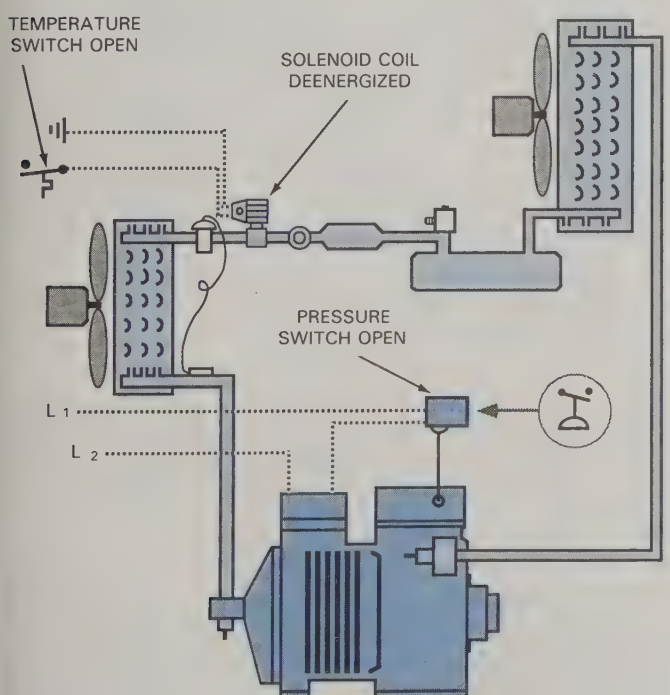


Fig. 15-19. In the pumpdown ''off'' cycle, the open temperature switch cuts current to the solenoid coil, closing the valve and stopping refrigerant flow. The compressor will keep running until the pressure switch opens (just before suction line pressure reaches a vacuum). This results in all refrigerant being removed from the low side of the system after each run cycle.

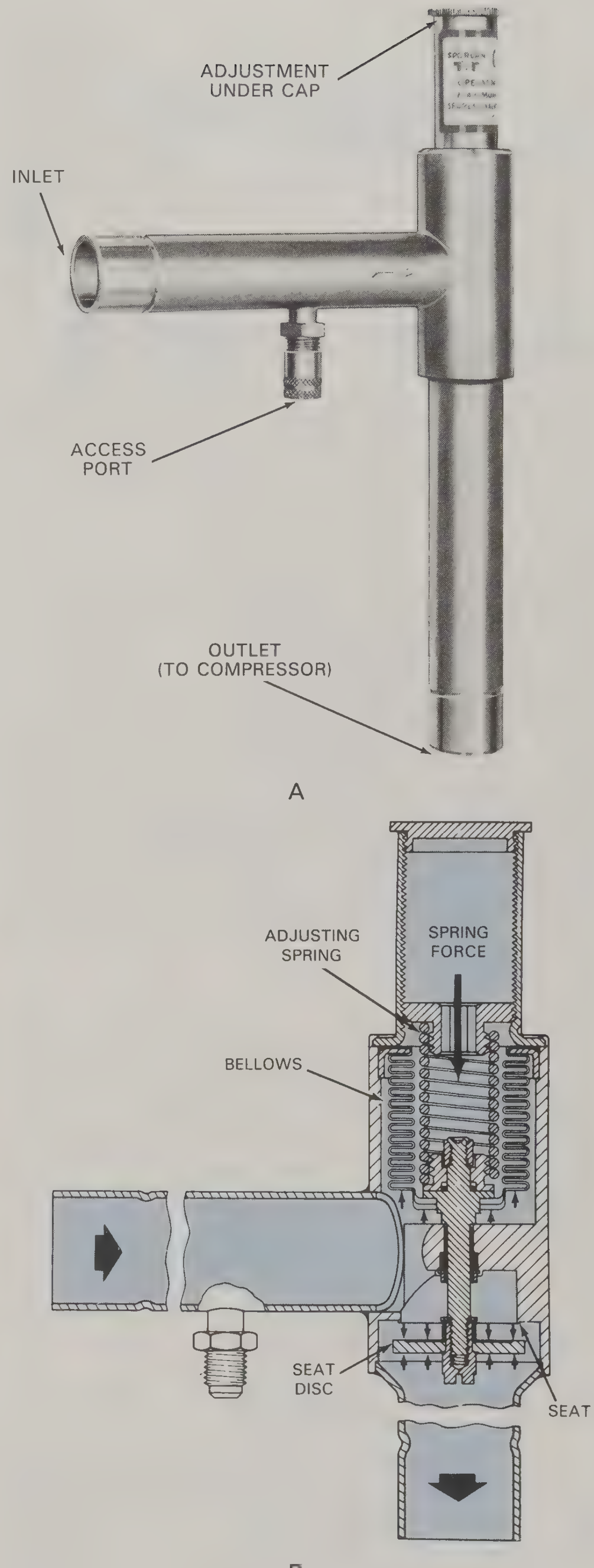


Fig. 15-20. CPR valve. A–Valve spring adjustment is under cap. Note direction-of-flow arrow on body. B–Cutaway view shows component locations. (Sporlan Valve Co.)

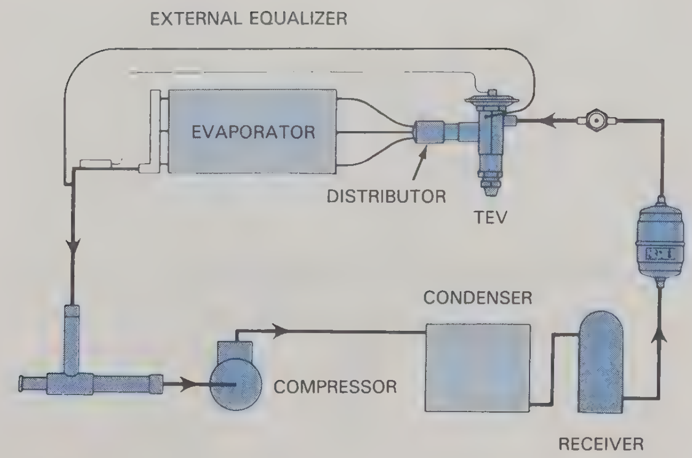


Fig. 15-21. In a typical system, the CPR valve is mounted in the suction line just before the compressor. It limits compressor inlet pressure, protecting the compressor. (Sporlan Valve Co.)

sive pressure. When suction pressure exceeds the CPR setting, the valve will throttle the pressure down to the valve setting. When suction pressure is reduced to the valve setting, the CPR is fully open.

High suction pressure typically occurs after a defrost cycle when the evaporator is very warm. If such high suction pressure is allowed to enter the compressor, it will cause very high condensing pressure. This condition overloads the compressor, causing it to short cycle on the overload until the suction pressure is lowered to normal conditions. Short cycling increases the amount of oil pumped out of the crankcase. Severe oil pumping causes broken piston rods, dry bearings, and damaged valve reeds.

CPR adjustments

The CPR is adjusted by turning a screw located under the cover cap. When adjusting the valve, the gauge manifold is installed on the suction service valve (SSV) to obtain accurate readings of pressure *entering the compressor*. Most CPRs are set to limit entering suction pressure to 18-20 psig (124-138 kPa). Pressure adjustments can only be made when suction pressure (on the inlet side of the valve) *exceeds* the valve setting. Accurate adjustments cannot be made when the valve is fully open, a condition that occurs whenever low side pressures are below the valve setting.

DISCHARGE BYPASS VALVES

Refrigeration and air conditioning systems are usually designed to provide a specific capacity at maximum load conditions. Large systems must make provision for operation at *reduced* load conditions to maintain temperature and *humidity* (air moisture) control. Discharge bypass valves are one method used to control humidity and load variations. Some systems control capacity by compressor cylinder unloading or by using two or more compressors (multiplexing). On multiple compressor systems, individual compressors are turned off as the load and suction pressure is reduced.

It is often necessary to limit minimum evaporator pressure during periods of low load. This prevents frost or ice formation on the evaporator and avoids operating the compressor at low suction pressures. Without such ***capacity control,*** the compressor would cycle on and off and rapidly reduce its lifespan. Such on-off control of air conditioning systems permits wide temperature variations and does a poor job of controlling humidity. Human comfort requires control of both temperature and humidity.

Valve application

A practical and economical solution to the problem is to *bypass* a small portion of hot discharge gas directly into the low-pressure side. The amount of hot gas bypassed is controlled by installing a modulating control valve, called a ***discharge bypass valve.*** See Fig. 15-22A. This valve opens on a decrease in suction pressure and can be set to automatically maintain a desired *minimum* evaporator pressure. Hot gas only bypasses when suction pressure is reduced to the valve setting. This method places a "false load" on the evaporator to maintain a minimum suction pressure.

Valve location

The discharge bypass valve is installed in a branch line off the hot gas discharge line, as close to the compressor as possible. See Fig. 15-22B. The hot gas is piped to the low pressure side at the evaporator inlet or directly into the suction line. The evaporator inlet is the preferred location, because the thermostatic expansion valve will respond to the increased superheat leaving the evaporator and provide the liquid required for desuperheating. The evaporator also serves as an excellent mixing chamber for the bypassed hot gas and the liquid-vapor mixture from the expansion valve. Oil return from the evaporator is improved since the velocity in the evaporator is increased by the hot gas.

It is recommended that a solenoid valve be installed ahead of the bypass valve. The solenoid valve is only energized during the run cycle. This permits the system to operate with automatic pumpdown and guards against leakage during the "off" cycle.

Valve operation

Discharge bypass valves respond to changes in suction pressure. When suction pressure is above the valve setting, the valve remains closed. As the suction pressure drops below the valve setting, the valve begins to open. As with all modulating valves, the amount of opening depends upon what is being controlled (in this case, the suction pressure). As the suction pressure continues to drop, the valve opens wider until the limit of the valve piston stroke is reached. However, in normal

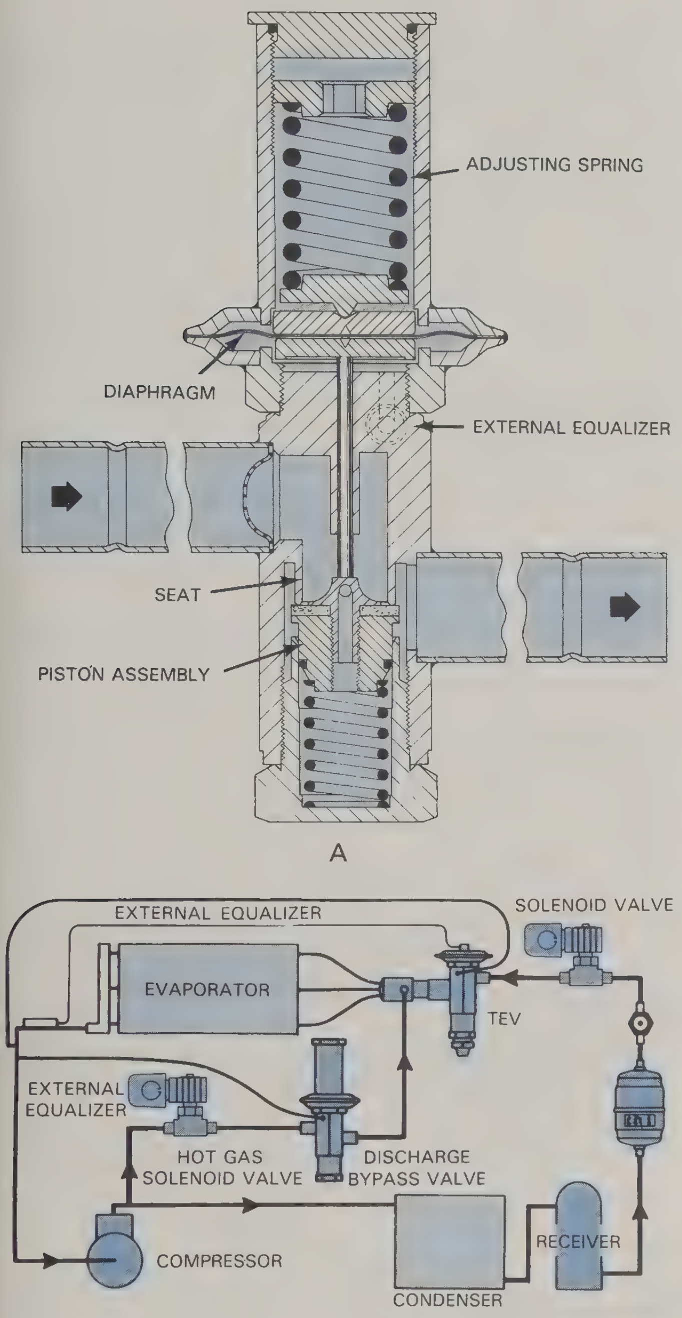


Fig. 15-22. Hot gas (discharge) bypass valve. A–Cutaway view of adjustable hot gas bypass valve. B–Location of hot gas bypass valve. (Sporlan Valve Co.)

applications, the amount of pressure change is seldom sufficient to open the valve to the limit of its stroke.

Discharge bypass valves are usually rated at 6°F (3.3°C) temperature change between closed position to rated opening. A typical application would be a low-temperature compressor designed to operate at a minimum suction gas temperature on R-22 of -40°F (0.5 psig). The required suction temperature at normal load conditions is -30°F (4.9 psig). A discharge bypass valve would be selected to start opening at 3.0 psig (the pressure equivalent to -34°F) and bypass enough hot gas at 0.5 psig (-40°F) to prevent further decrease in suction pressure.

Many large air conditioning systems use hot gas bypass to prevent evaporator freeze-up and short cycling of the compressor. The hot gas bypass valve begins opening at 60 to 61 psig (using R-22). See Fig. 15-23 for a valve used in this type of application.

DESUPERHEATING THERMOSTATIC EXPANSION VALVE

On those applications where hot gas must be bypassed directly into the suction line, an extra thermostatic expansion valve is required. This valve is commonly called a ***desuperheating TEV*** or liquid injection valve. See Fig. 15-24.

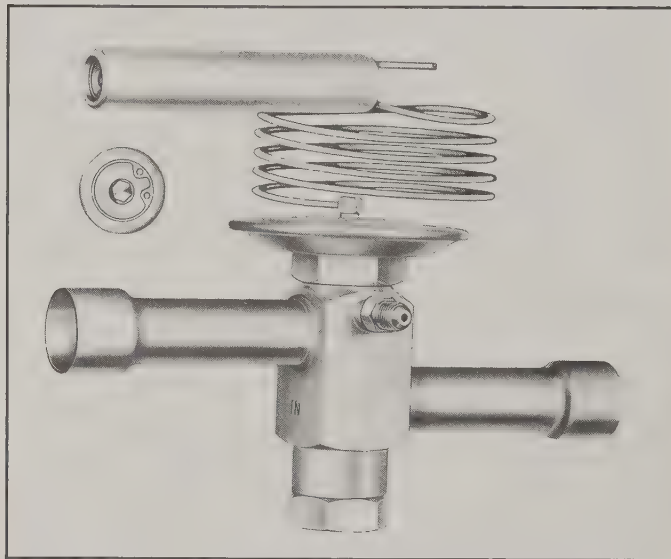


Fig. 15-23. Hot gas bypass valve used in large systems to prevent evaporator freeze-up. (Sporlan Valve Co.)

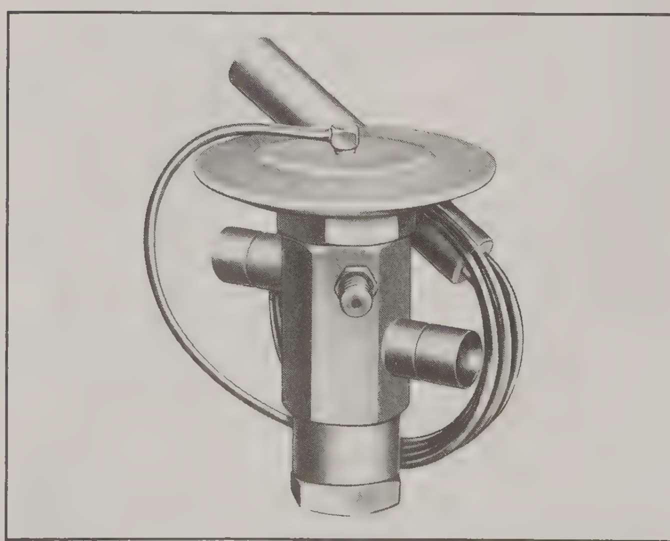


Fig. 15-24. A desuperheating thermostatic expansion valve used for hot gas bypass systems. (Sporlan Valve Co.)

The purpose of this valve is to supply enough liquid refrigerant to cool the hot discharge gas to the recommended suction temperature. This protects the compressor from being overheated by high suction gas temperatures. Hot gas entering the suction line must be desuperheated to remain within the suction temperature limits specified by the compressor manufacturer. Again, a solenoid valve is installed in the liquid injection line to permit an automatic pumpdown cycle and to prevent leakage during the off cycle.

Proper mixing of the hot gas, liquid injection, and suction gas is important. The compressor must be protected at all times against high suction temperatures due to superheat and liquid floodback. Proper mixing of these "additives" to the suction line must be obtained. Several mixing methods are available, but the one generally recommended is arranged so that the discharge gas (and liquid injection) enters the suction line at an angle of flow which is against the direction of gas flow in the suction line. See Fig. 15-25.

Arranging a bypass directly into a suction accumulator is often a convenient way to obtain proper desuperheating of suction gas. In any event, introducing the hot gas and liquid into the suction line with separate connections is not generally recommended.

CONTROLLING HEAD PRESSURE

Many commercial systems place the air-cooled condensing unit outdoors, often on the roof. This conserves space inside the building and permits using outdoor ambient air for condenser cooling. Outdoor units perform very well, but cold winter temperatures present problems because of low head pressure. Many air conditioning systems must operate during the winter months to provide controlled environments. Provision must be made, in such applications, to maintain proper head pressure during periods when ambient temperatures are low.

The high-side pressure must be sufficient to maintain proper pressure drop across the thermostatic expansion valve. For proper operation of the TEV, certain minimum head pressures are required. Valves used with R-12 require a head pressure of 100 psig; 180 psig is required for R-502, and 200 psig for R-22. When head pressure drops too low, the expansion valve cannot feed properly. When head pressure goes down, suction pressure also goes down. This results in poor refrigeration and/or an iced evaporator.

Low ambient temperatures cause low head pressure on air-cooled condensing units, as can be observed by installing a gauge manifold. The gauges reveal low pressures on each side, and the sight glass shows many bubbles (flash gas). The system contains the proper amount of refrigerant for summer operation, but not for winter operation.

Air-cooled condenser capacity is selected to provide for efficient operation at 90°F ambient airflow. Cold ambient airflow greatly increases condenser capacity, resulting in low head pressure. This low head pressure is not adequate to push liquid out of the receiver and maintain correct pressure drop across the expansion valve. Liquid backs up in the receiver and just lies there.

A *temporary* solution to the problem is adding enough refrigerant to partially fill the condenser with liquid. Filling the condenser with liquid reduces its capacity, causing head pressure to rise. When the outdoor ambient temperature rises, however, head pressure will rise drastically, due to decreased condenser capacity. The system will cycle on the overload (or high pressure

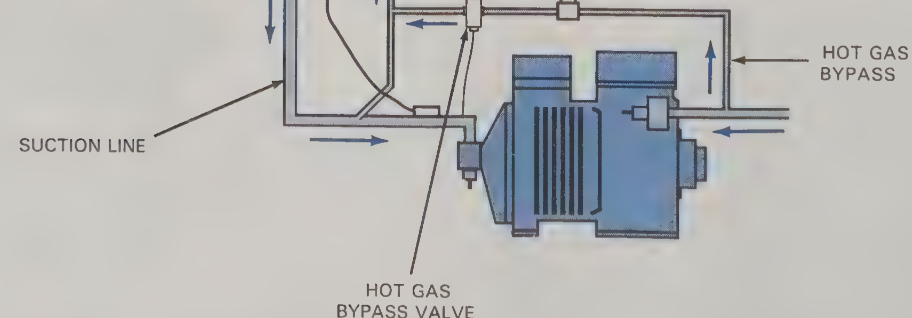


Fig. 15-25. Arrangement for liquid injection into the suction line to desuperheat the hot gas entering the line.

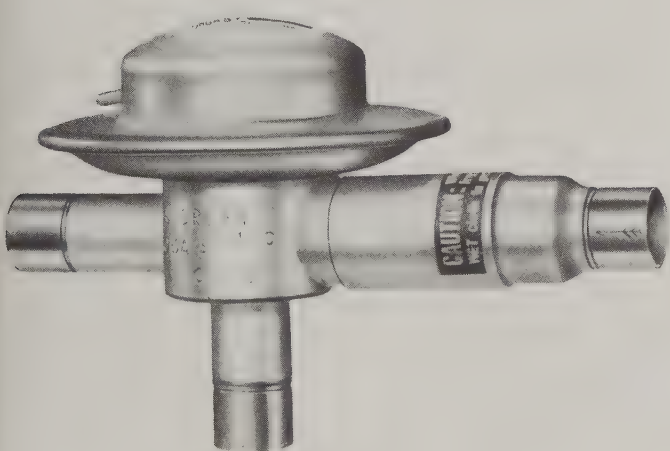
safety control). The excess refrigerant must be removed from the system to return the condenser to normal capacity. Head pressure will return to normal ... until winter arrives again.

Solving low head pressure problems

Two common types of ***head pressure control valves*** are used to solve low head pressure problems caused by low ambient temperatures. One method uses a single valve that is nonadjustable. The other uses two valves, and is fully adjustable.

Nonadjustable valve. The nonadjustable head pressure control valve will maintain 100 psig head pressure for R-12, or 180 psig for R-502, and 200 psig for R-22. These are three-way modulating valves controlled by discharge pressure. See Fig. 15-26.

When head pressure drops to the valve setting, the valve will direct some (or all) hot gas to bypass the condenser and travel directly to the receiver, Fig. 15-27. The valve modulates in any position to control the amount of bypass that maintains proper head pressure. Under extreme conditions, the liquid receiver will act as the condenser, due to cold ambient temperatures.



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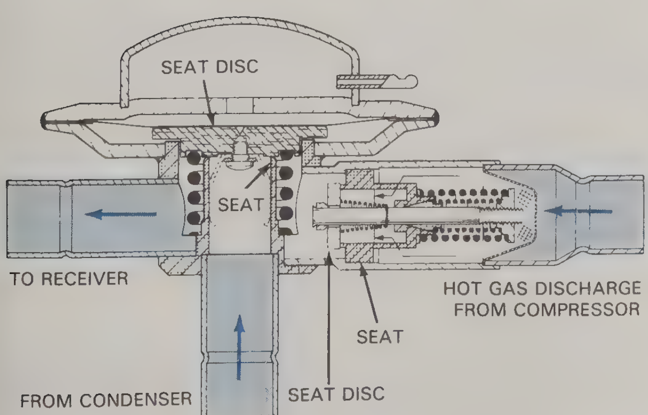

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Fig. 15-26. Head pressure control. A–Nonadjustable head pressure control valve. B–Cutaway view of valve shows components. (Sporlan Valve Co.)

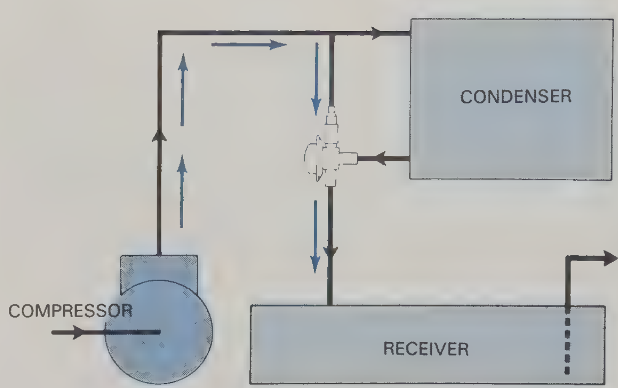


Fig. 15-27. When head pressure drops sufficiently, the valve allows hot gas to bypass the condenser and go directly to the receiver. (Sporlan Valve Co.)

Principle of valve operation. The charge in the valve dome exerts pressure on top of the diaphragm, which controls the seat disc. This downward diaphragm pressure tends to open the seat disc, permitting gas to bypass directly to the receiver. The discharge (or condensing) pressure pushes upward on the diaphragm. This upward pressure tends to close the valve and prevent bypassing. Proper discharge pressure keeps the valve closed, so the condenser is fully operational.

When discharge pressure falls below diaphragm pressure, the valve opens and allows discharge (bypass) gas to be metered into the receiver. This creates a higher pressure at the condenser outlet. When the valve opens to permit hot gas to bypass, the condenser outlet line is restricted, causing liquid to back up inside the condenser. When the valve is fully open, the condenser outlet is fully closed. The beauty of this valve is that it can modulate and thus control the amount of liquid in the condenser, according to ambient temperature. Head pressure is maintained by controlling condenser capacity.

All head pressure control valves require the use of a liquid receiver large enough to hold the total charge for both summer and winter operation. Excess refrigerant is needed during cold weather to permit proper flooding of the condenser. These valves are only used on systems having a thermostatic expansion valve.

Manufacturers of outdoor condensing units usually include a head pressure regulating valve and an oversized liquid receiver. All other components are sized for normal operation. The liquid receiver must be oversized because good refrigeration practice states that the total system charge should not exceed 75 percent of receiver capacity. The excess charge needed for winter operation must be included in the receiver capacity.

Head pressure control valves should not be used on systems without a liquid receiver, or on systems where the receiver is too small. A lack of receiver storage space will cause liquid to back up in the condenser. When ambient temperatures begin to rise, this would cause discharge pressure to become excessively high due to liquid refrigerant reducing condenser capacity.

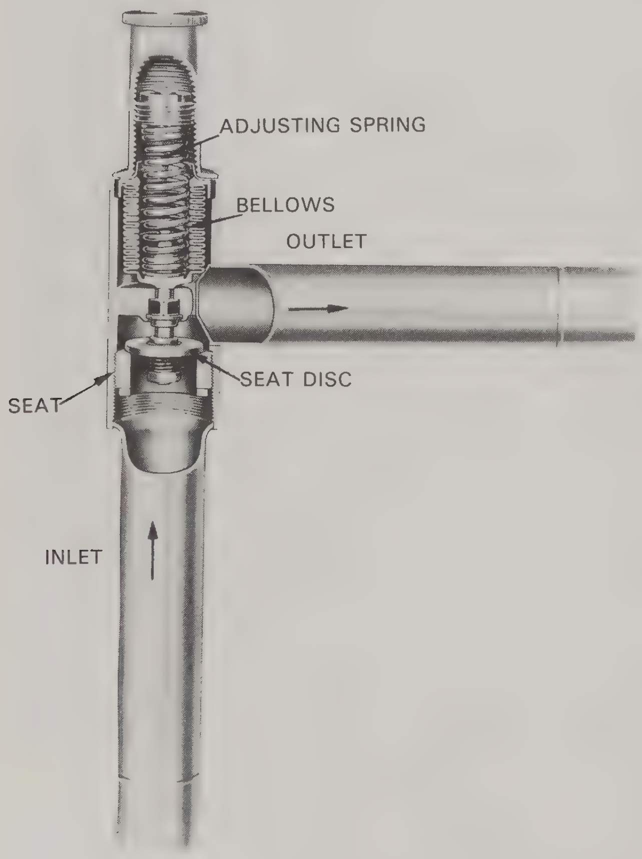
Adjustable valves. The adjustable head pressure control valve is combined with a differential valve to provide an improved system of head pressure control. See Fig. 15-28. These valves provide another method of maintaining constant receiver pressure during all types of low ambient conditions. These head pressure valves can be used for all common refrigerants such as R-12, R-22, or R-502, because they are adjustable over a range of 65 to 225 psig.

As shown in Fig. 15-29, the adjustable valve is located in the liquid line between the condenser and liquid receiver. The differential valve is located in a hot gas line bypassing the condenser.

Valve operation. During periods of low ambient temperature, head pressure falls until it approaches the setting on the adjustable valve. The valve then throttles down, restricting flow of liquid from the condenser. Liquid backs up in the condenser and reduces condenser capacity. This raises condensing pressure.

Since it is actually *receiver* pressure that needs to be maintained, the bypass line with the differential valve is needed. The ***differential valve*** is preset for 20 psig, and opens when the pressure difference between the receiver and hot gas discharge exceeds that value. Hot gas flowing through the bypass line heats up the cold liquid being passed by the adjustable valve. As a result, the liquid is warm when it reaches the receiver and has sufficient pressure to properly feed the expansion valve.

With proper refrigerant charge, the two valves modulate refrigerant flow automatically in order to maintain proper receiver pressure regardless of outside ambient temperatures.



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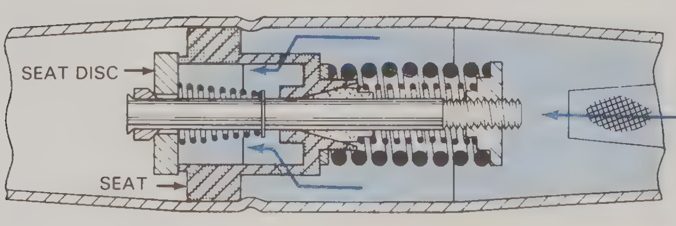


B

Fig. 15-28. Head pressure control. A–Cutaway of adjustable-type head pressure control valve. B–Cutaway of differential valve. (Sporlan Valve Co.)

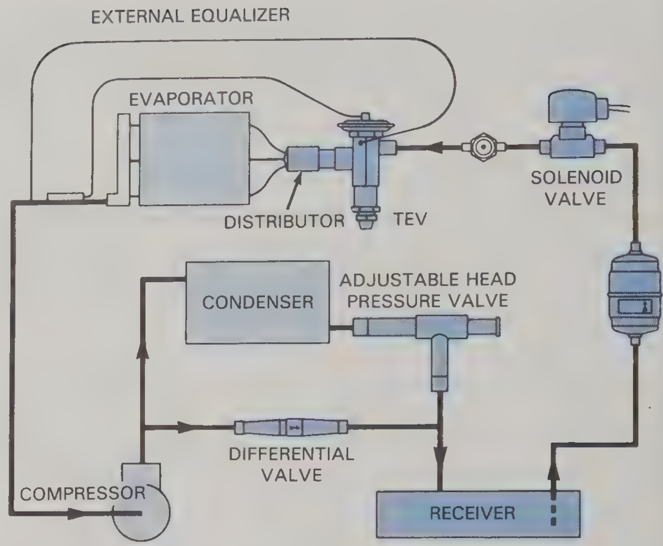


Fig. 15-29. The adjustable head pressure valve and the differential valve work together to control receiver pressure. (Sporlan Valve Co.)

BRAZING VALVES TO TUBING

When brazing these valves into the system, wrap the valve body with a *wet* cloth to prevent heat damage by keeping the body temperature below 250°F (118°C). The torch tip should be large enough to avoid prolonged heating of the copper connections. Always direct the flame away from the valve body and perform the brazing operation quickly and carefully.

SUMMARY

It is important that you understand the intent and operation of special purpose valves. Service technicians frequently encounter such valves on different systems. The valves serve a special purpose in each situation for proper control of the circulating refrigerant. Any malfunction by the special purpose valves will greatly affect system operation. Installing and adjusting these valves

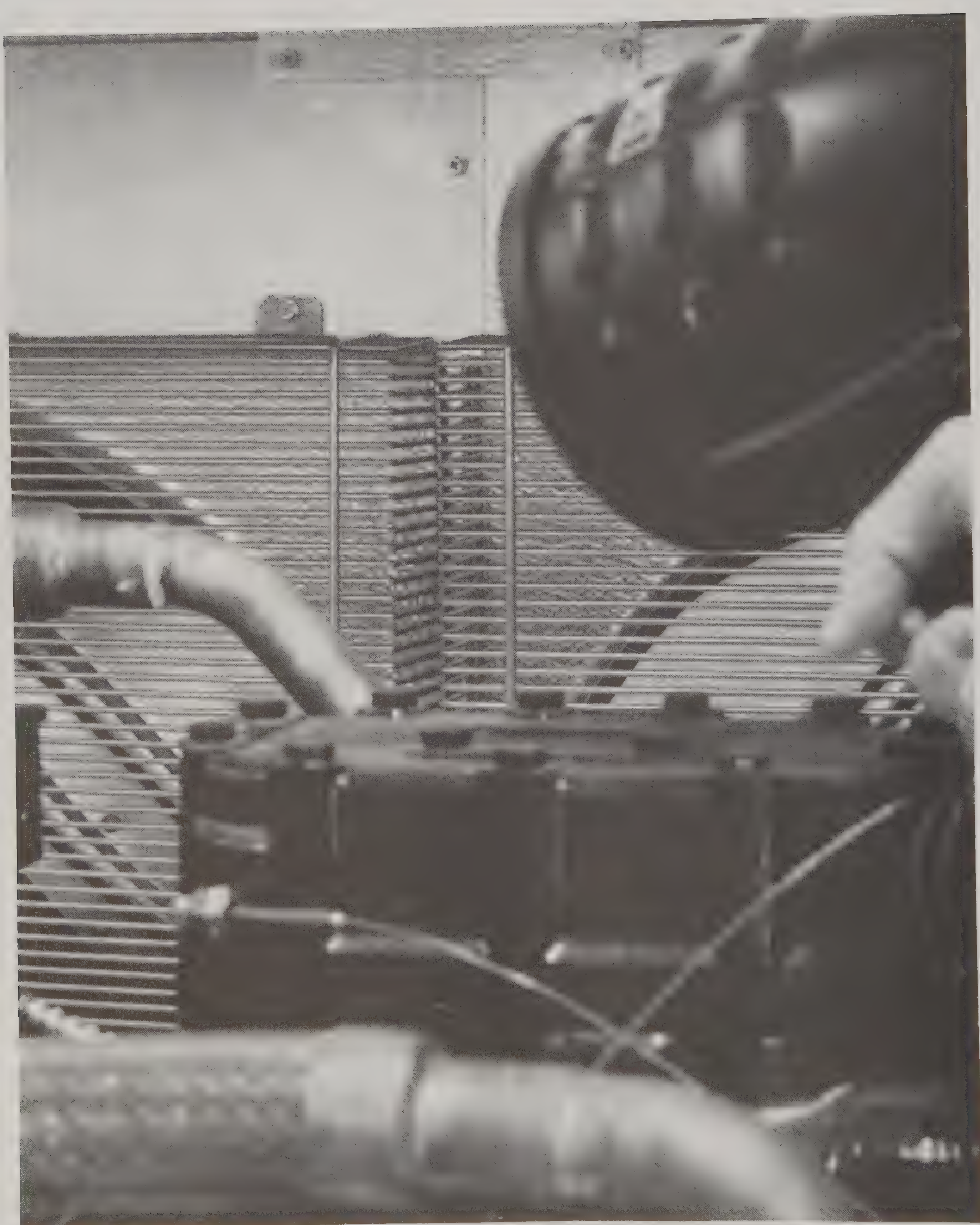
is quite easy, but you must understand their purpose and how they affect the system.

Hand valves are installed for the benefit of the service technician, and prove very useful for isolating sections of the system. Electrically actuated solenoid valves are frequently used to control refrigerant flow. Special pressure regulating valves serve to protect system components and improve system efficiency.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name three types of hand valves.
2. Check valves are used to prevent __________ flow.
3. EPRs are used to keep __________ pressure from falling below a setpoint.
4. EPRs are also referred to as __________ valves.
5. EPRs are installed anywhere in the __________ line.
6. True or false? EPRs are adjusted before adjusting TEV superheat.
7. Where are multiplex systems often used?
8. A solenoid valve operates on __________.
9. When energized, are solenoid valves normally open or closed?
10. Name a common refrigeration example of a use for a solenoid valve.
11. CPR valves limit pressure entering the __________.
12. Name two methods used to control reduced load conditions.
13. What is the purpose of a desuperheating TEV?
14. Will cold ambient airflow over the condenser increase or decrease condenser capacity?
15. What is minimum head pressure for R-12? R-22? R-502?



An aid in troubleshooting refrigeration systems is a leak detection system that uses a fluorescent tracer dye and an ultraviolet light source. The dye is added to the refrigerant oil, and the system is allowed to operate for a time. Leakage will show up as bright yellow stain under ultraviolet light. (H. B. Fuller Company)

Chapter 16

TROUBLESHOOTING FLOW CONTROLS

After studying this chapter, you will be able to:
- *Diagnose and correct problems in AEV or TEV systems.*
- *Identify and rectify capillary tube problems.*
- *Recognize and properly use various types of hand valves.*
- *Diagnose EPR and CPR valve problems and make necessary adjustments.*
- *Identify problems and make repairs needed for correct operation of solenoid valves.*
- *Diagnose and correct problems in head pressure control and discharge bypass valves.*

NEW WORDS

amperage	isolated
case	migrate
condensate water drain	overcharging
erratic	slugging
evaporator freeze-up	troubleshooting
evaporator load	undercharged

TROUBLESHOOTING

The process called ***troubleshooting*** involves the logical gathering of information needed to make an intelligent decision about a system problem. Once the decision has been made, the technician can take the necessary steps to correct the problem. When troubleshooting the various flow controls used in refrigeration systems, the service technician *must* know how the devices operate and how to make corrective adjustments. Such knowledge eliminates mistakes and avoids creating problems where none previously existed. Flow controls are very important to the efficient operation of the system and only rarely need adjustment or replacement. Problems with refrigerant flow controls most often can be traced to faulty installation or to poor service techniques.

Every system problem can be reduced, finally, to one of two basic causes:

1. Refrigerant not moving properly.
2. Refrigerant quantity is insufficient (system is undercharged).

TROUBLESHOOTING THE AEV

The automatic expansion valve (AEV) prevents evaporator pressure from dropping below a specified level. The compressor must be able to remove excess pressure from the evaporator. Also, the AEV cannot control evaporator pressure during the off cycle. The AEV is usually a very reliable system component.

Undercharged system

An ***undercharged*** system is one that suffers from a lack of refrigerant. Proper system pressures cannot be maintained without sufficient refrigerant in the system. Many AEV systems do not have a sight glass for determining refrigerant charge. Troubleshooting the AEV is best performed with the gauge manifold, taking pressure readings from both sides of the system. Trouble with the AEV is usually indicated when evaporator pressure becomes too low. The valve may be defective, the valve setting may be wrong, or the system may be low on refrigerant. See Fig. 16-1.

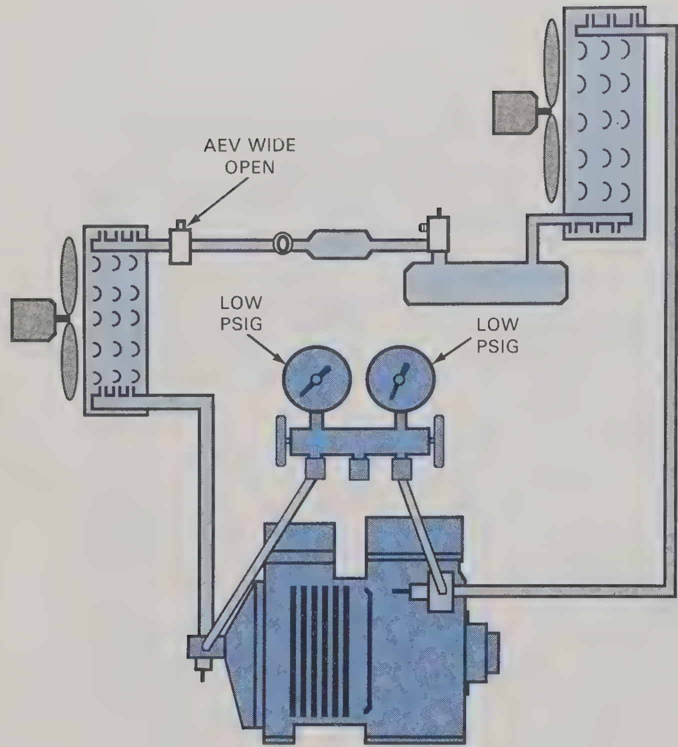


Fig. 16-1. When the system is undercharged, the AEV cannot feed properly. The low-side pressure reading may be deceptive, because the valve will try to maintain a constant pressure.

The valve cannot feed properly unless sufficient liquid is present. When the system is undercharged, a low side pressure reading will be deceptive because the valve will try to maintain a constant pressure. The valve may be wide open, but sufficient liquid is not available to increase evaporator pressure.

An undercharged system must be checked for leaks. When found, the leak must be repaired and the repair tested. It will be necessary to change the filter-drier, then evacuate and recharge the system.

Erratic valve settings

A valve that is ***erratic*** does not maintain a particular setting for any length of time. If the refrigerant charge is correct, but the AEV requires periodic readjustment, then the valve should be replaced. An erratic valve is difficult to identify and requires thorough examination of other possibilities.

Contaminants

Erratic valve operation can also be caused by a foreign substance (ice, sludge, or wax) fouling the valve seat. Ice, sludge, or wax can be detected by turning off the system and warming the valve with hot water. *Do not use a torch!* Heat will loosen or melt the foreign matter, so it will pass through the valve. The AEV will then work properly until the contaminants once again foul the valve seat. A contaminated system can be cleaned by changing the filter-drier as often as necessary to restore proper cleanliness.

Poor cooling, low head, normal suction

The customer may complain, "the system is not cooling right. The product temperature is high and the system runs all the time." The gauges reveal low head pressure, but suction line pressure is acceptable. Low on refrigerant? Maybe. Check for bubbles in the sight glass. The sight glass may show a full charge. Adding more refrigerant (***overcharging***) will raise the head pressure, but will not cure the problem. See Fig. 16-2.

The compressor may have defective internal valve reeds or a broken piston rod. The compressor will run, but is unable to draw gas and compress it properly. The compressor is performing at half its normal capacity. The low-side pressure will be normal because the AEV is choked down to match the lower capacity of the compressor. The low rate of refrigerant removal from the evaporator will result in very slow lowering of product temperature.

A defective compressor is usually indicated by *lower-than-normal* discharge pressure, and *higher-than-normal* suction-line pressure. This particular problem was more difficult, because the AEV maintained a normal suction pressure.

Poor cooling, high head, normal suction

Poor cooling with long running time is frequently caused by high head pressure. See Fig. 16-3. Pressure drop across the AEV is excessive. It results in extra "flash gas," which increases evaporator pressure. High head pressure causes the AEV to throttle down, resulting in reduced cooling capacity and long running time. The AEV will maintain constant suction pressure, but head pressure will be higher than normal. Correcting head pressure will cure the problem, permitting the valve to feed subcooled liquid.

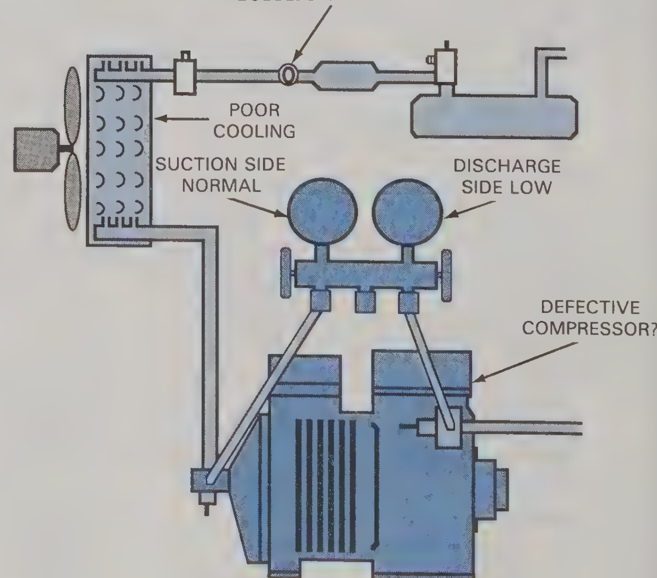


Fig. 16-2. Possible causes of low head pressure and poor cooling include undercharging and a defective compressor.

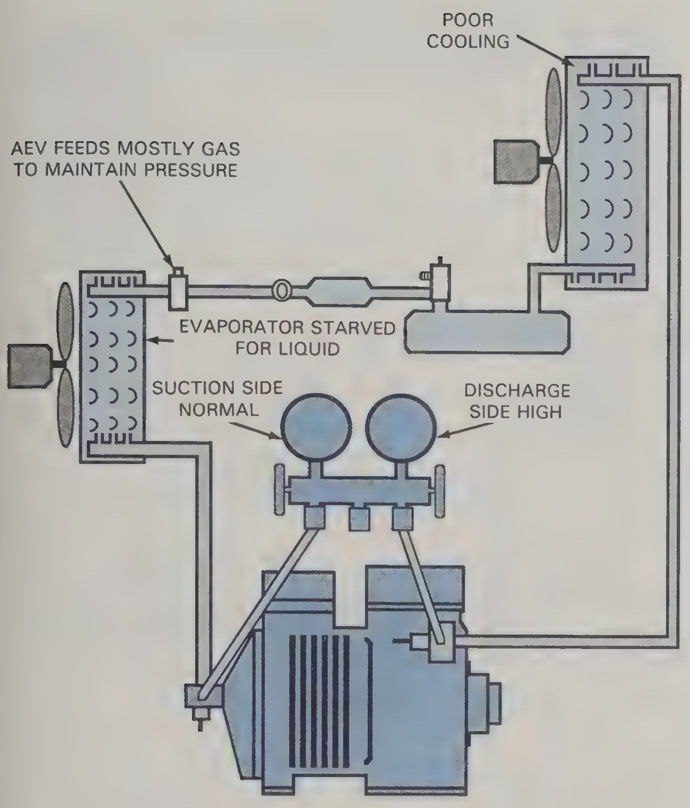


Fig. 16-3. High head pressure causes the AEV to throttle down, ''starving'' the evaporator by feeding more gas than liquid. Cooling capacity of the system is reduced significantly.

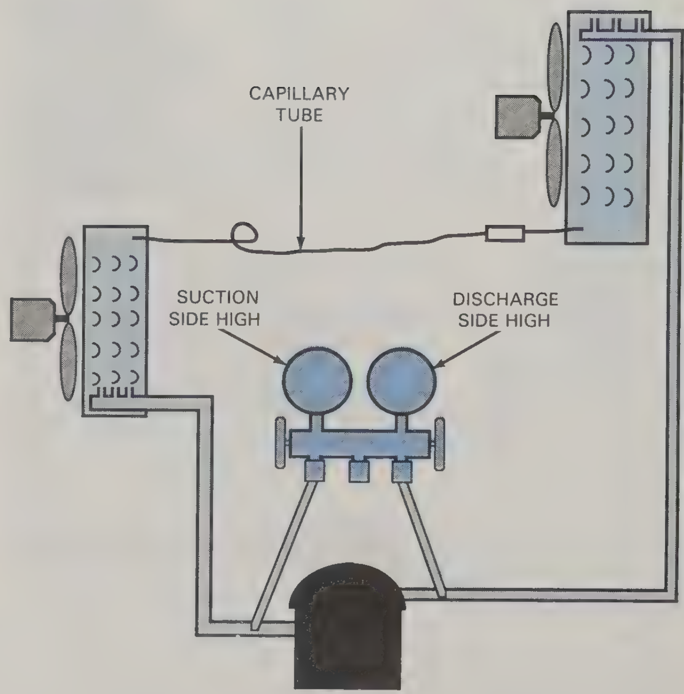


Fig. 16-4. Major causes of high head pressure in a capillary tube system are a dirty condenser or a defective condenser fan. High head pressure can also be caused by a refrigerant overcharge, by air in the system, or by high suction line pressure.

TROUBLESHOOTING THE CAPILLARY TUBE SYSTEM

Since it does not have service valves, troubleshooting the capillary tube system requires maximum use of eyes, ears, and hands. Use of saddle valves is a last resort. It is normal for a capillary tube ("cap tube") to make a gurgling sound as liquid enters the evaporator. It pays to become familiar with this sound: a gurgle indicates liquid, while a whistle indicates vapor.

Poor cooling, high head, high suction

The most frequent problems encountered with a capillary tube system are a dirty condenser or a burned-out condenser fan. Each of these situations causes high head pressure, which in turn causes high suction pressure (and temperature), and excessive running time. When normal head pressure is restored, suction line pressure is also corrected and the evaporator pressure/temperature returns to normal. This permits proper cooling and shorter running time. See Fig. 16-4.

Undercharged evaporator

In a capillary tube system, *low* head pressure can be caused by an undercharged evaporator. This condition is revealed by partial frosting of the evaporator. The frost line is incomplete due to improper flooding of the evaporator (and low suction pressure).

The most common (but *incorrect*) method of overcoming an undercharged evaporator is to add refrigerant; the result is usually a compressor motor burnout due to a system overcharge.

The fact that a *partially restricted capillary tube* can cause an evaporator to be undercharged is a surprise to most technicians. The restriction causes liquid to back up in the condenser and become subcooled. The resulting low suction pressure results in low head pressure. See Fig. 16-5.

Overcharging the system will increase head pressure because more liquid backs up inside the condenser, reducing its capacity. The higher head pressure overcomes the partial restriction, producing higher suction line pressure. However, because condenser capacity has been reduced by the overcharge, higher suction pressure produces even higher head pressure.

Overcharging a system only compounds the problem of a restricted capillary tube. Product temperature can be reduced to the proper level, although head pressure will be excessive. When the system shuts off, more time will be needed to reduce the excessive head pressure before restarting.

The problem occurs when the thermostat requires a system restart before head pressure is reduced. The compressor will shortcycle on the overload until head pressure is reduced. Continued shortcycling leads to compressor motor burnout.

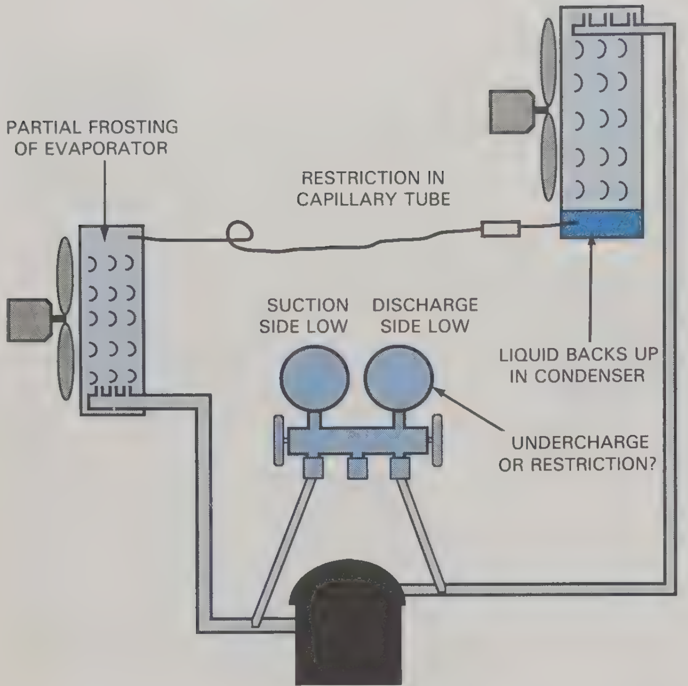


Fig. 16-5. A restriction in the capillary tube will cause undercharging of the evaporator. Adding refrigerant may overcharge the system, leading to a burned-out compressor motor.

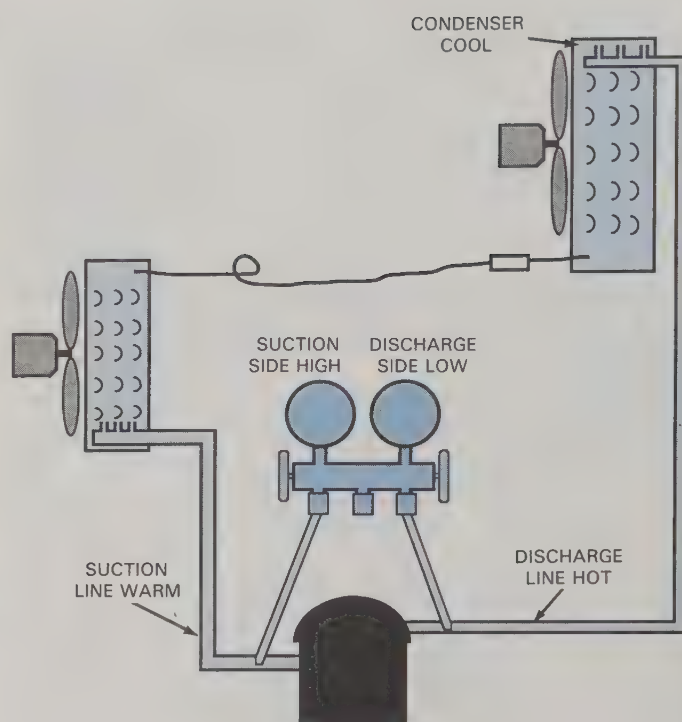


Fig. 16-6. A defective valve reed or a broken piston rod in the compressor can cause poor cooling performance. Suction line pressure will be high, and discharge pressure low.

The undercharged evaporator situation can be very misleading. To rely on appearance and a low pressure reading will only add to the problem. The most reliable method of diagnosing a restriction is to include a high pressure reading and check ***amperage*** (current flow) to the compressor. Low amperage indicates the compressor is loafing; high amperage indicates an overload. Electricity and amperage readings are explained later.

Poor cooling, low head, high suction

Suction pressure on capillary tube systems will change along with discharge pressure. When one goes up, the other goes up. When one goes down, the other goes down. The *only* exception to this rule is the effect of a defective compressor: high suction pressure with low discharge pressure. See Fig. 16-6. Defective valve reeds or a broken piston rod make the compressor inefficient and unable to compress refrigerant properly. Compressor replacement is indicated.

Defective compressor symptoms are a cool condenser (low head pressure) and a warm suction line (high suction pressure), combined with low power usage and a hot gas discharge line that is very hot. The compressor is loafing (indicated by a low amperage draw) and very little refrigerant is moving through the system. The hot gas is mostly moving back and forth between the compressor and the hot gas discharge line. The compressor discharge valve reed is supposed to prevent backflow of gas into the compressor after being discharged. Broken or damaged compressor valve reeds result in an inefficient compressor. Compressor replacement is indicated. Compressor operation is explained later in more detail.

Working with capillary tubes

Capillary tubes are easily damaged. Kinks, sharp bends, and vibration should be avoided. It is sometimes necessary to cut off one or two inches where the tube was brazed into the filter-drier. When cutting a capillary tube, care must be exercised to avoid closing the hole. See Fig. 16-7. Proper procedure is to use a file or knife blade to make a notch (cut) in the tubing. The

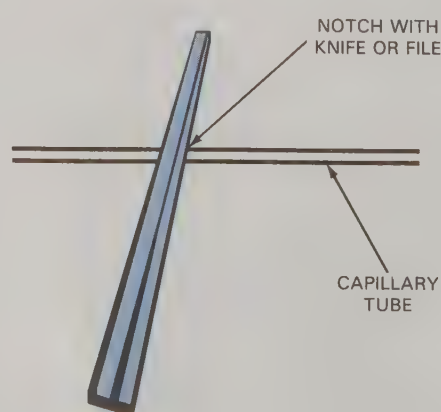


Fig. 16-7. Proper method for cutting a capillary tube, without closing the hole, is to first notch the tube with a knife or file. Then, bend the tubing back and forth until it breaks at the notch.

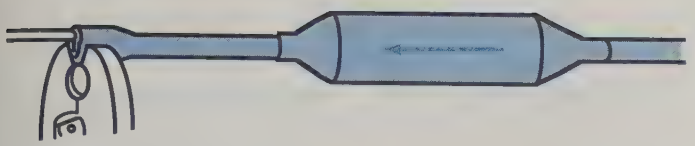


Fig. 16-8. Before brazing, carefully crimp the copper tube of the filter-drier over the capillary tube. Do not pinch the capillary tube shut. Use only a small amount of alloy when brazing.

tubing is then bent back and forth at the notch until tubing breaks off.

Extreme care must be exercised when brazing the capillary tube to a filter-drier. As shown in Fig. 16-8, insert two or three inches of the capillary tube into the filter-drier and carefully crimp the copper tube onto the capillary tube. Use care not to crimp the capillary tube. Perform brazing quickly and use very little alloy. The alloy must not be permitted to follow the capillary tube inside the filter-drier and plug the capillary opening. The possibility of alloy plugging the capillary tube is increased by excessive or prolonged heating of the joint, or by using excess alloy.

Moisture

Moisture cannot be tolerated in a capillary tube system. One drop of moisture freezing inside the capillary tube will completely plug the tiny passage through the tubing. The system will continue to run, but liquid refrigerant cannot move past the ice plug. The evaporator becomes very warm and low side pressure drops to a vacuum. Head pressure goes down, as a result of low suction pressure. If the system is turned off until the ice plug melts, it will again operate perfectly for a period of time (until the drop of moisture once more freezes inside the capillary tube).

Good service technique is needed when working on capillary tube systems to prevent contamination. Any time that a capillary tube system is opened for repairs (such as fixing a leak), it *must* be thoroughly evacuated and the filter-drier replaced prior to recharging. Capillary tube systems allow no margin for error.

TROUBLESHOOTING THE TEV

Proper TEV performance is easily determined by measuring superheat at the evaporator outlet. Thus, checking superheat is the first step in diagnosing TEV performance. A starved evaporator results in high superheat. Excessive liquid flooding of the evaporator causes low superheat. Although both these symptoms point to improper TEV superheat control, the actual cause most often is elsewhere. Always check for proper installation of the thermal bulb and external equalizer.

Water, or a mixture of water and sludge, freezing at the valve seat can lock the TEV closed, open, or partly open. This problem greatly affects proper flooding of the evaporator and can cause high superheat, low superheat, or no superheat.

Shut the system off and use warm water (*Never* a torch!) to warm the TEV valve body and melt the obstruction. Restart the system and recheck superheat. The valve should return to normal operation. Check the moisture indicator and change filter-drier.

High superheat

An undercharged system will prevent the TEV from feeding properly and result in high superheat. This situation is signaled by a hissing sound at the valve, bubbles in the sight glass, low suction pressure, and low head pressure. Gas bubbles in the sight glass can also be caused by noncondensibles (air) in the system, or by a partially restricted filter-drier.

Restricted filter-drier

A partially restricted filter-drier becomes cold and possibly covered with frost. A restricted filter-drier is caused by a screen plugged with contaminants, *not* by moisture. When a filter-drier has absorbed all the moisture it can hold, additional moisture passes through the filter-drier and freezes at the valve. Moisture cannot plug or restrict a filter-drier.

Improperly seated valve

Dirt, sludge, or foreign material lodged in the valve seat may prevent the TEV from seating properly. Liquid refrigerant may pass through the valve during the off cycle and fill the evaporator with refrigerant. (If the seat leak is severe, the valve will feed too much refrigerant during the run cycle, as well.) A valve seat leak is detected by a gurgling or hissing sound during the off cycle. Also, the sight glass may indicate continued flow for a long period after shutdown. Disassemble the valve to determine if dirt or foreign material is responsible for the leaky seat. Replace the TEV if the seat is damaged.

Dead thermal bulb

If the thermal bulb loses its charge, the TEV cannot open. The capillary tube connecting the thermal bulb to the valve diaphragm is often a cause of trouble. For example, excess vibration causes the tube to become work-hardened and break off. Vibration is normally caused by air flow from the evaporator fan. Vibration of the coils against one another, or against the evaporator can wear a hole in the soft capillary tube. The TEV must be replaced when the thermal bulb loses its charge.

Low evaporator load

Low ***evaporator load*** describes a condition in which the heat load cannot reach the evaporator surface. Low evaporator load causes the evaporator to become too cold. See Fig. 16-9. Under a low evaporator load condition, a smaller amount of liquid is needed to maintain proper superheat, so the TEV restricts flow. This causes

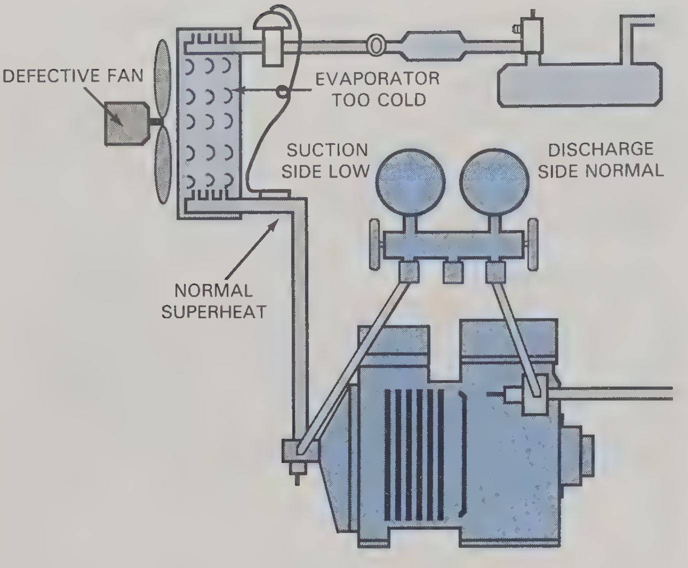


Fig. 16-9. A low evaporator load causes the evaporator to become too cold. A defective fan is one of a number of possible causes of insufficient air flow past the evaporator.

low suction line pressure, a colder evaporator, and normal superheat. Low evaporator load can be caused by insufficient air over the evaporator, undersized blowers, dirty air filters, frost formation on the evaporator, or low temperature of the entering air. Correct the condition responsible for low heat load.

Liquid migration

In a system where the condensing unit is located outside, if the ambient outdoor temperature is colder than the indoor evaporator, gaseous refrigerant will ***migrate*** (travel) to the compressor during the off cycle (since the compressor is colder than the evaporator, and heat travels hot to cold).

The cold ambient temperature also causes vapor inside the compressor to condense to a liquid. Upon restarting, the compressor must pump *liquid,* rather than *vapor* (a condition called ***slugging***). Liquid slugging can cause severe compressor damage. This particular situation is not caused by the TEV.

Crankcase heater. Any compressor located in cold ambient temperatures should be equipped with a crankcase heater, Fig. 16-10. This is an electric heater, fastened to the crankcase, that keeps the oil warm under cold conditions. Warm oil keeps condensation from forming in the crankcase, as well as preventing liquid migration.

Most condensing units located in areas where cold ambient temperatures occur are equipped with a liquid line solenoid valve for automatic pumpdown. The pumpdown removes refrigerant from the low pressure side before system shutdown.

TROUBLESHOOTING MULTIPLEXED EVAPORATORS

Troubleshooting a multiplexed evaporator system is fairly easy, because the problem can usually be isolated to a particular area. For example, if one ***case*** (individual cooling system) is having problems and other cases on the system are functioning normally, the problem is inside that one case. See Fig. 16-11. Each case contains

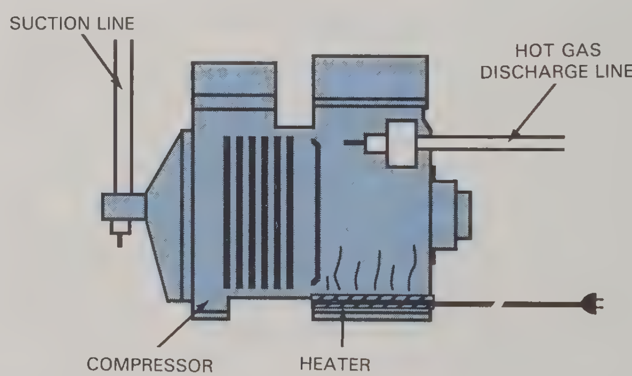


Fig. 16-10. An electrical heater at the bottom of the compressor warms oil in the crankcase under cold ambient conditions. This keeps condensation from forming, and eliminates damaging slugging by preventing liquid migration.

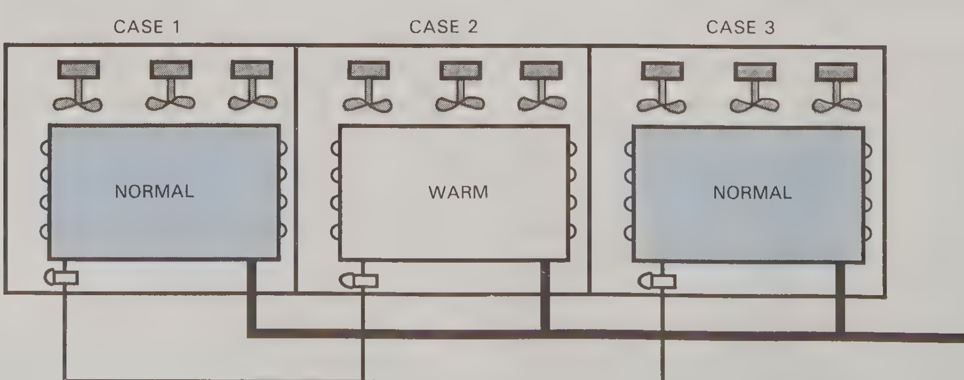


Fig. 16-11. In a multiplexed evaporator system, problems can usually be isolated to one case. In this example, there is a problem in Case 2, but Cases 1 and 3 are operating normally.

an evaporator, TEV, fans, condensate water drain, defrost heaters, and other components. A malfunction of any of these components will create problems within one case only.

Proper air flow over the evaporator and product must be maintained at all times. Improper air flow will cause the product temperature to rise, because the heat load is not reaching the evaporator. Reduced heat load causes the TEV to choke down and create a very cold evaporator. A colder evaporator accumulates more frost, which further restricts air flow.

Each case is supplied with a ***condensate water drain***, which can become plugged. Accumulated water inside the case can cause several kinds of problems: it can leak onto the floor, cause fan blades to break off, or burn out fan motors. Accumulated water freezing in frozen food cases can cause damage to equipment and product. Failure of the *defrost heater* will permit the evaporator to accumulate excessive frost. Defrost systems are explained later.

Evaporator freeze-up

The term ***evaporator freeze-up*** describes an evaporator that has become totally restricted by frost and ice buildup. The TEV cannot recognize this problem and will continue to maintain a constant superheat, regardless of evaporator condition or temperature. Severe freeze-ups may result in floodback problems due to a very cold evaporator.

Freeze-ups are normally caused by poor loading of the evaporator resulting from inadequate airflow through the evaporator. The airflow problem may result from a burned-out fan, dirty filters, or other causes. It is necessary to remove all frost and ice from the evaporator and correct the loading problem. The TEV will function properly when the evaporator is clean and the airflow problem has been corrected.

Condensing unit problems

If all cases in a multiplexed evaporator system have the same problem, then a condensing unit malfunction should be suspected. This could involve high head pressure, loss of refrigerant, a blown fuse or circuit breaker, compressor problems, defrost timer problem, or shutdown by a safety control. Motor controls and safety controls are explained later.

USING HAND VALVES

An example of good use of hand valves is illustrated by a hand shut-off valve installed immediately after the sight glass. The filter-drier and sight glass are normally located immediately after the liquid receiver outlet service valve (LRSV). See Fig. 16-12.

When the LRSV is front-seated (closed), and the hand valve is closed, the filter-drier is ***isolated*** (blocked off) and easily changed. Pumpdown and time-consuming service procedures are eliminated.

System pumpdown

Another method of changing the filter-drier is accomplished by manually pumping down the system. The high pressure gauge (red) hose is connected to the liquid receiver service valve port. With the system running, frontseat the LRSV. The compressor will remove all refrigerant from the low pressure side, all the way back to the LRSV. All refrigerant is stored inside the receiver, condenser, and hot gas discharge line.

The compressor should be stopped just before the system enters a vacuum state. If the compressor is not stopped before a vacuum is achieved, "kill" the vacuum by briefly cracking the LRSV. Release just enough liquid refrigerant from the receiver into the low side of the system to raise its pressure to 1 or 2 psig.

The hand valve is closed only when the liquid line pressure is slightly above a vacuum. This isolates the

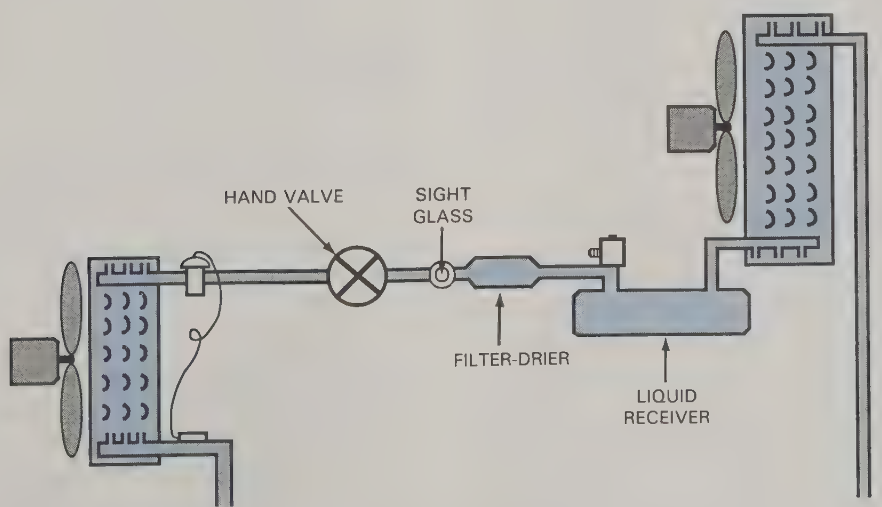


Fig. 16-12. Installing a hand shut-off valve immediately after the sight glass allows easy isolation and changing of the filter-drier.

filter-drier, so it can be removed and replaced. The small amount of refrigerant vapor remaining inside the filter-drier will escape, preventing atmospheric air from entering. A replacement filter-drier should be at hand so that removal and replacement can be done quickly.

After replacement, the LRSV is opened, but the hand valve is not.

Before opening the hand valve, the filter-drier and sight glass are pressurized with liquid and checked for leaks, using a soap bubble solution. When connections are leak free, both valves are fully opened and the gauge hose removed. The system is then turned on.

Any hand valve that will not open or close properly should be replaced. Repairs are not recommended. Refrigerant leaking from around the valve stem is rare, but indicates a defective valve.

TROUBLESHOOTING EPRs

When installing EPRs with brazed connections, wrap the valve with a wet cloth to keep the body temperature below 250°F (121°C). The torch tip should be large enough to avoid prolonged heating of the connections. Overheating can be reduced by directing torch flame away from the valve body. Be careful to avoid running alloy into the internal parts of the valve.

Some EPRs are hermetic and cannot be disassembled for inspection and cleaning. They must be replaced if they become inoperative. If an EPR fails to open or close properly, or if it will not adjust, solder or other foreign materials lodged in the port may be at fault. It is sometimes possible to dislodge these materials by turning the adjustment nut all the way out with the system running. Once cleared, the valve can be reset.

If the EPR develops a refrigerant leak around the spring housing, it probably has been overheated during installation or the bellows has failed due to severe compressor pulsations. When the bellows fails, the EPR will close until the inlet pressure becomes greater than outlet pressure *plus* spring pressure. The EPR then becomes a *pressure differential* valve, and the evaporator pressure will change according to varying suction pressures. This produces an evaporator pressure higher than desired, and cannot be corrected. The valve must be replaced.

TROUBLESHOOTING SOLENOID VALVES

Troubleshooting a solenoid valve is primarily limited to determining whether or not the coil is energized. The coil cannot be energized unless proper voltage is applied to it–no voltage, no magnetism. Electricity and methods for checking voltage are explained in later chapters.

To quickly determine if the coil is energized, hold the tip of a small steel screwdriver close to the top center of the coil. See Fig. 16-13. If the coil is energized, magnetism will pull the screwdriver tip downward. If the coil is not energized, the screwdriver will not be pulled toward the coil. This magnetic field is not very strong, so a *small* screwdriver is required for proper detection.

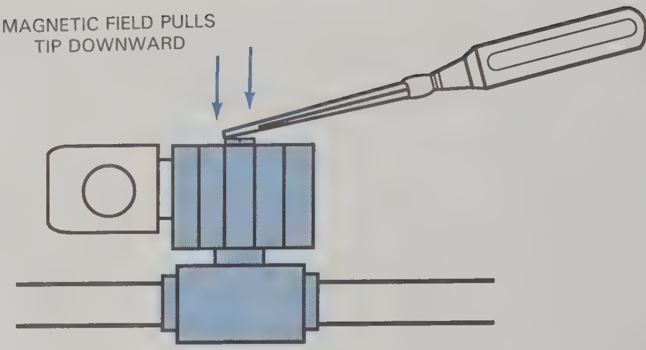


Fig. 16-13. A small steel screwdriver can be used to test for an energized solenoid coil. Magnetic force will pull the screwdriver tip downward if the coil is energized.

Solenoid valves are noiseless during normal operation. A steady humming sound (alternating current hum) indicates the coil is not correctly positioned or not properly anchored to the valve. Solenoid valves normally make a sharp "snap" sound when energized. This sound is caused by the plunger striking the top of the enclosing cylinder. To check solenoid operation, energize and deenergize the coil while listening for the snapping sound.

Coil burnouts are rare, and are normally caused by improper wiring or improper voltage. A burnout can occur, however, if the plunger is not free to be pulled upward when magnetic force is exerted. This problem usually is caused by a damaged enclosing tube. A burnout also occurs if the coil is removed from the valve while energized.

Failure of the valve to open or close properly is normally caused by foreign material lodged in the valve seat. This problem can also be caused by a valve body that is deformed due to overheating. A defective solenoid coil is easily replaced, but a defective valve body requires replacement of the entire valve.

TROUBLESHOOTING HEAD PRESSURE CONTROLS

There are several possible causes for malfunctions in systems with head pressure controls. These problems can be difficult to isolate from each other. Troubleshooting is not a "guessing game." Information must be obtained to narrow the problem to a specific area or component. Operating temperatures and pressures must be known before system problems can be pinpointed.

Fig. 16-14 is a table that lists causes of most common malfunctions involving head pressure controls, and the recommended solution to those problems.

Troubleshooting head pressure control valves can sometimes be performed by using your bare hands to determine how the valve is feeding. During very cold ambient temperatures, the valve should be completely

LOW HEAD PRESSURE	
POSSIBLE CAUSE	REMEDY
Low charge, cannot flood condenser.	Add refrigerant.
Low pressure setting on valve.	Increase setting.
Valve fails to close due to foreign material stuck in valve.	Open valve wide open to pass material. If unsuccessful, replace valve.
Valve will not adjust.	Replace valve.
Valve fails to close due to loss of element charge.	Replace valve.
Valve fails to open.	Replace valve.
HIGH HEAD PRESSURE	
POSSIBLE CAUSE	REMEDY
Dirty condenser.	Clean condenser.
System overcharged.	Purge until proper head pressure is obtained.
Undersized receiver.	Check receiver capacity.
Air in system.	Purge air from system
Valve fails to adjust or open.	Replace valve.
Bypassing hot gas when not required.	Replace valve.

Fig. 16-14. Possible causes and remedies for head pressure problems.

bypassing the condenser; the bypass line to the liquid receiver should be warm. When ambient temperatures are high, the valve should be fully closed, and the bypass line should be cold. Also, with a proper charge in the system, the head pressure should not drop below 100 psig (690 kPa) for R-12 and 200 psig (1379 kPa) for R-22 and R-502. In addition to checking the temperature of the copper tubing, always check pressures and observe the liquid level in the sight glass.

A system that is low on refrigerant will normally exhibit low head pressure. However, the head pressure control valve will bypass in its attempt to maintain proper head pressure. This condition is revealed by a very warm receiver and an empty or low liquid level in the sight glass. The valve is working properly, but the system suffers from an undercharge.

TROUBLESHOOTING DISCHARGE BYPASS VALVES

There are two basic problems with a discharge bypass valve (DBV): failure to open and failure to close. Failure to open is revealed by low suction pressure. Failure to close is revealed by high suction pressure.

Problems with the DBV are often caused by foreign material lodging inside the valve. These valves can usually be disassembled for cleaning. Defective sensing elements are replaceable without changing the entire valve.

SUMMARY

Troubleshooting refrigerant flow controls involves systematic gathering of information for making a decision. Hasty decisions usually result in a wrong diagnosis and a recall. For proper troubleshooting, you must take the time to analyze the problem. When proper information is available, the decision is obvious. Guesswork is eliminated by information. Hands, ears, eyes, thermometers, and the gauge manifold are all useful tools for gathering information.

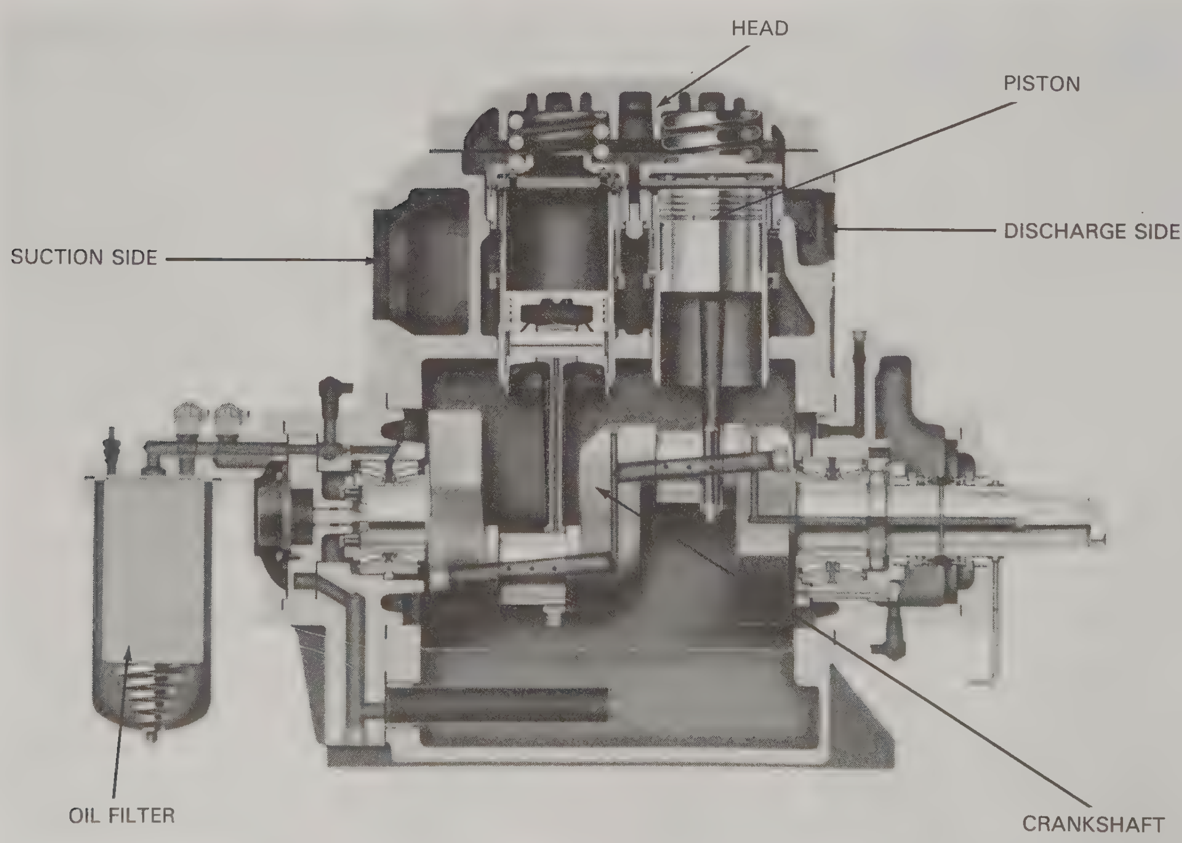
The technician must know how each valve operates and what purpose it serves in the system. A malfunction by one particular valve can cause problems throughout the system. It is important to be able to narrow the problem down to the valve responsible. When the source of the problem is corrected, other system components usually will function properly.

This chapter has presented many methods of troubleshooting system components. Each type of system requires different logic and reasoning. The chapter covers the most common problems associated with refrigerant flow controls. More important, it explains the methods used to diagnose and isolate system problems.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name the two basic system problems.
2. List the symptoms that indicate an undercharged AEV system.
3. An inefficient compressor is usually indicated by _________ head pressure and _________ suction pressure.
4. Poor cooling with long running time is usually caused by _________ pressure.
5. True or false? On capillary tube systems, high head pressure causes high suction pressure.
6. Name three possible causes of an undercharged evaporator on a capillary tube system.
7. Describe the proper way to cut a capillary tube.
8. What is the first step to take in diagnosing TEV performance?
9. Evaporator freeze-ups are normally caused by poor _________.
10. Manual pumpdown is performed when changing the _________.
11. EPRs are easily damaged by _________ from torches.
12. Whether a solenoid coil is energized can easily be checked by using a small _________.
13. A sharp _________ sound signals that a solenoid valve has been energized.
14. If the _________ is not free to moved when a solenoid coil is energized, the coil can burn out.
15. Name two basic problems with discharge bypass valves.



An open-type compressor, like this large six-cylinder model, is more serviceable in the field than semi-hermetic types. The cutaway view shows the key components. (Vilter Mfg. Co.)

Chapter 17
COMPRESSORS

After studying this chapter, you will be able to:
- *Identify five types of compressors.*
- *List the advantages of the compliant scroll compressor.*
- *Identify the three major compressor designs.*
- *Discuss the operation of each type of compressor.*
- *Describe the advantages offered by the discus compressor.*
- *Identify the components of a reciprocating compressor.*
- *Align pulleys and flywheels.*
- *Select, size, and replace V-belts.*

NEW WORDS

access opening
augers
centrifugal
clearance pocket
compliant
crankshaft
direct drive
disc-type compressor valve
flywheel
full-floating
hermetic
orbiting
piston
piston rings
reciprocating
rotary
rotor
rpm
scroll
semi-hermetic
stubs
valve plate
valve reed
vanes
volume
volute

WHAT IS A COMPRESSOR?

The compressor is a mechanical pump that circulates refrigerant. It is the heart of any refrigeration system, and is the most expensive and vital component of the system. A compressor malfunction will greatly affect operation of other components. Compressor problems are diagnosed without breaking into the compressor to examine individual parts. Problems involving the compressor are considered major, due to time and expense of replacement or repair. The technician must fully understand how the compressor performs its duty. Knowledge eliminates confusion.

The purpose of the compressor is to remove heat-laden low temperature vapor from the evaporator and compress (squeeze) this vapor into a much smaller volume. As the ***volume*** is reduced, heat is concentrated in a smaller area and a much higher temperature results.

TYPES OF COMPRESSORS

The compressor is a mechanical device driven by an electric motor, and is available in five basic types:
- Reciprocating
- Rotary
- Screw
- Centrifugal
- Scroll

RECIPROCATING COMPRESSOR

The reciprocating compressor is the workhorse of the industry. It is used for domestic and commercial applications ranging from fractional horsepower up to

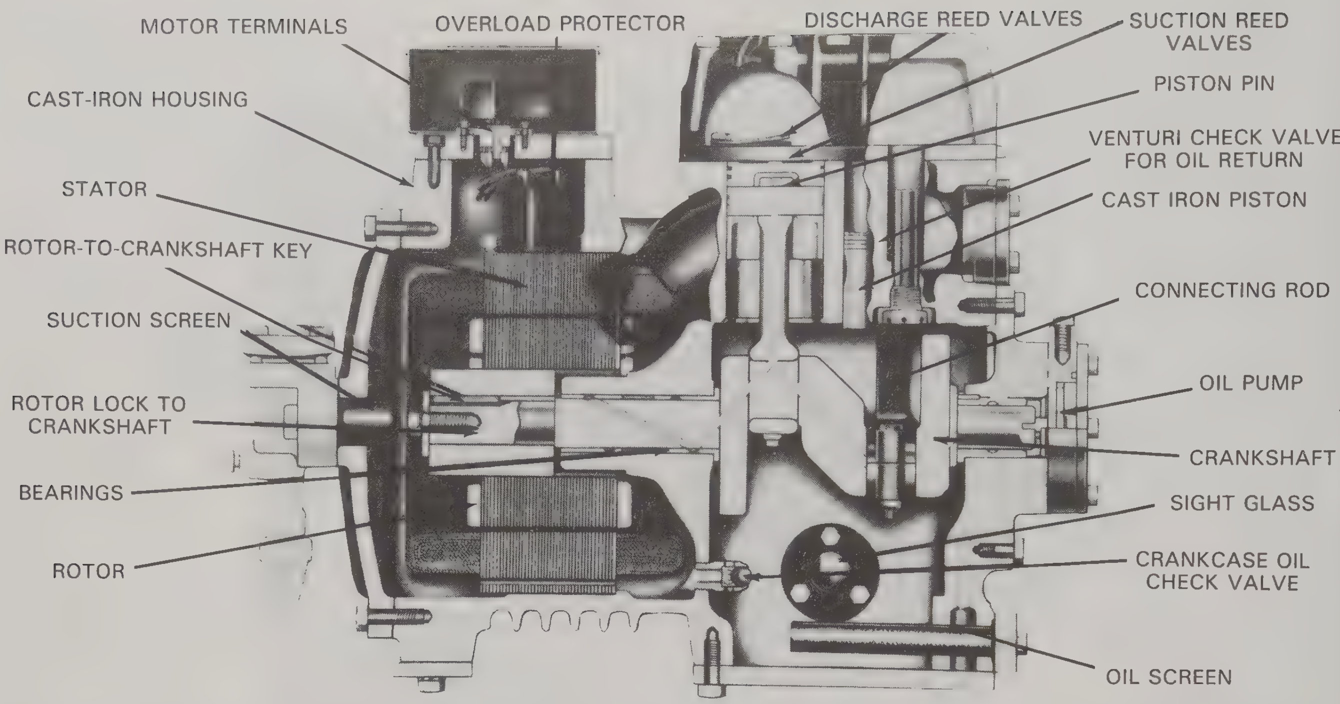


Fig. 17-1. This two-cylinder reciprocating compressor is typical of those used widely in refrigeration applications. (Copeland Corp.)

100- to 150-ton range. The ***reciprocating*** compressor operates much like an automobile engine. It has one or more pistons driven from a crankshaft that is turned by an electric motor. These pistons make alternate suction and compression strokes in a cylinder equipped with suction and discharge valve reeds. See Fig. 17-1.

ROTARY COMPRESSOR

There are two basic types of ***rotary*** compressors. One has blades that rotate with the eccentric (rotor); the other has stationary blades (***vanes***). Rotary compressors are so classified because they operate on a rotating or circular motion. The rotary compressor is a positive displacement unit and more efficient than a reciprocating compressor. See Fig. 17-2.

In the domestic field, rotary compressors are occasionally used in fractional horsepower sizes. Recently, the rotary has gained some use in the 1.5- to 5-ton residential air conditioning market. Large rotary compressors are sometimes used in low- temperature industrial systems.

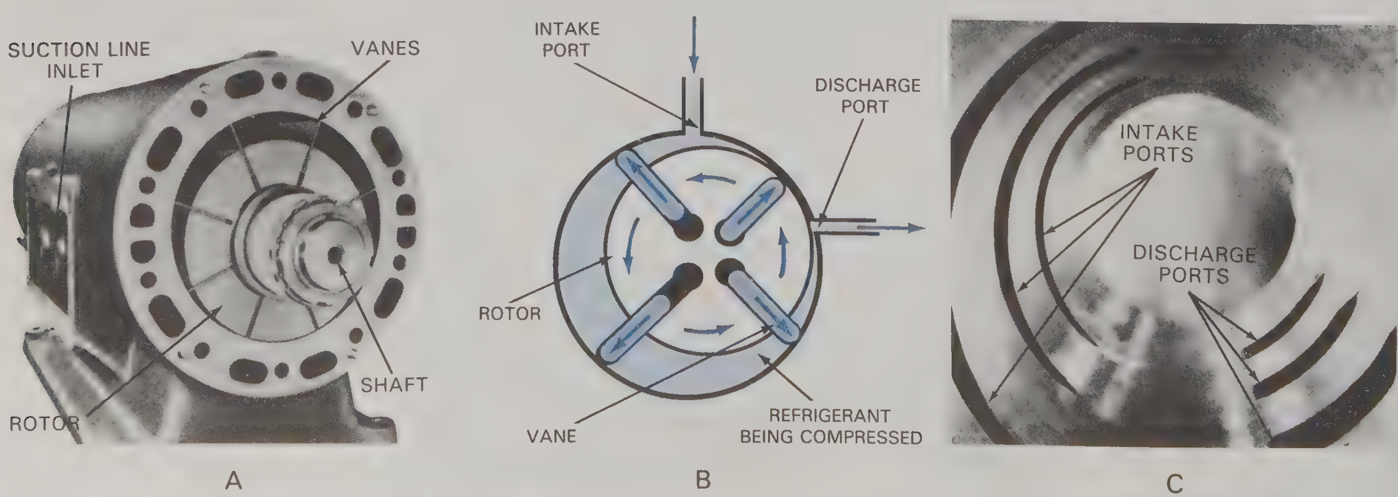


Fig. 17-2. Rotary compressor. A–Major components of the rotary compressor. B–The rotor is mounted off-center on the shaft so that, as it rotates, refrigerant in the space between the vanes is compressed into a smaller and smaller volume before being discharged. C–With rotor and shaft removed, the intake and discharge ports of the compressor are visible. Note that intake ports are much larger than discharge ports. (Fuller Co.)

SCREW-TYPE COMPRESSOR

The screw compressor uses a pair of matched ***augers*** (or "screws") to compress refrigerant gas. See Fig. 17-3. The vapor enters one end of the paired augers and is compressed as it travels to the other end and is discharged. Sizes of screw-type compressors currently in use for chilled-water systems range from 100 tons up to 700 tons. Screw machines also are used in large tonnage refrigeration and air conditioning systems of 20 tons and up.

CENTRIFUGAL COMPRESSOR

The ***centrifugal*** compressor is sometimes called the "turbo compressor" because it belongs to a group of turbo machines that includes fans, propellers, and turbines. See Fig. 17-4. Refrigerant vapor enters at the center of a rapidly spinning disc with radial blades (impeller vanes) on its surface. The disc is located inside a case called a ***volute***. The impellers force the vapor outward, using centrifugal force to compress the gas against the walls of the volute. A continuous flow of compressed gas exits through the discharge port. Because refrigerant flow is continuous, centrifugal compressors can handle a greater volume than other types. Centrifugal compressors currently start at the 80- to 100-ton range and extend to more than 8000 tons. The design and cost of centrifugal compressors make them impractical for systems of 50 tons or less.

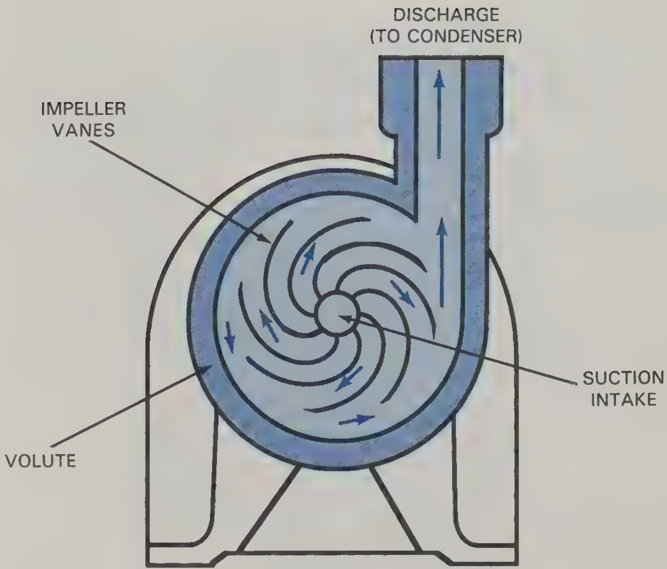


Fig. 17-4. Refrigerant gas is introduced at the center of the spinning disc, and forced outward by the impeller vanes. The centrifugal force exerted on the gas compresses it against the walls of the compressor, also called the "volute."

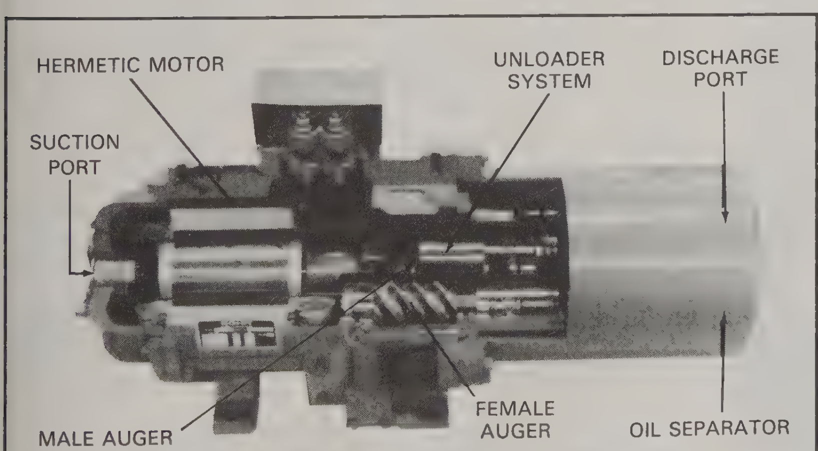
SCROLL COMPRESSOR

The ***scroll*** compressor was first patented in 1905, but only achieved widespread popularity in recent years. See Fig. 17-5. The concept of this compressor involves the mating of two spiral coils (scrolls) to form a series of crescent-shaped pockets. During compression, one scroll (the *fixed* scroll) remains stationary, while the other ***(orbiting)*** scroll *orbits* (but does not rotate) around the fixed scroll.

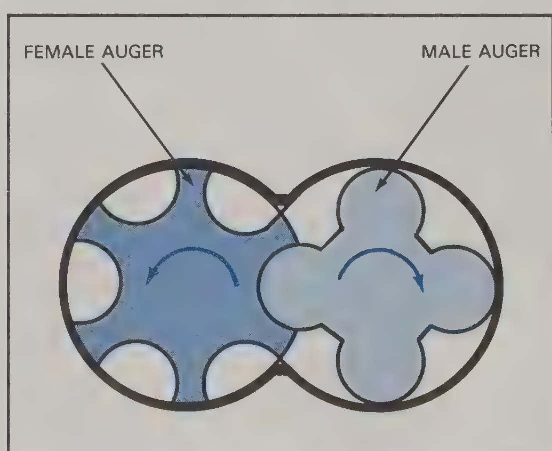
As shown in Fig. 17-6, the orbiting motion traps pockets of gas between the two scrolls. The gas is compressed by reducing pocket size as it is forced toward the center, where it is discharged. Several pockets of gas are compressed simultaneously during each orbit. Intake and discharge are continuous, providing smooth operation.

Advantages of the scroll compressor

Only two components, a fixed scroll and an orbiting scroll, are required to compress gas. These two components replace about 15 components in a typical piston-type compressor. Scroll compressors require no valves,

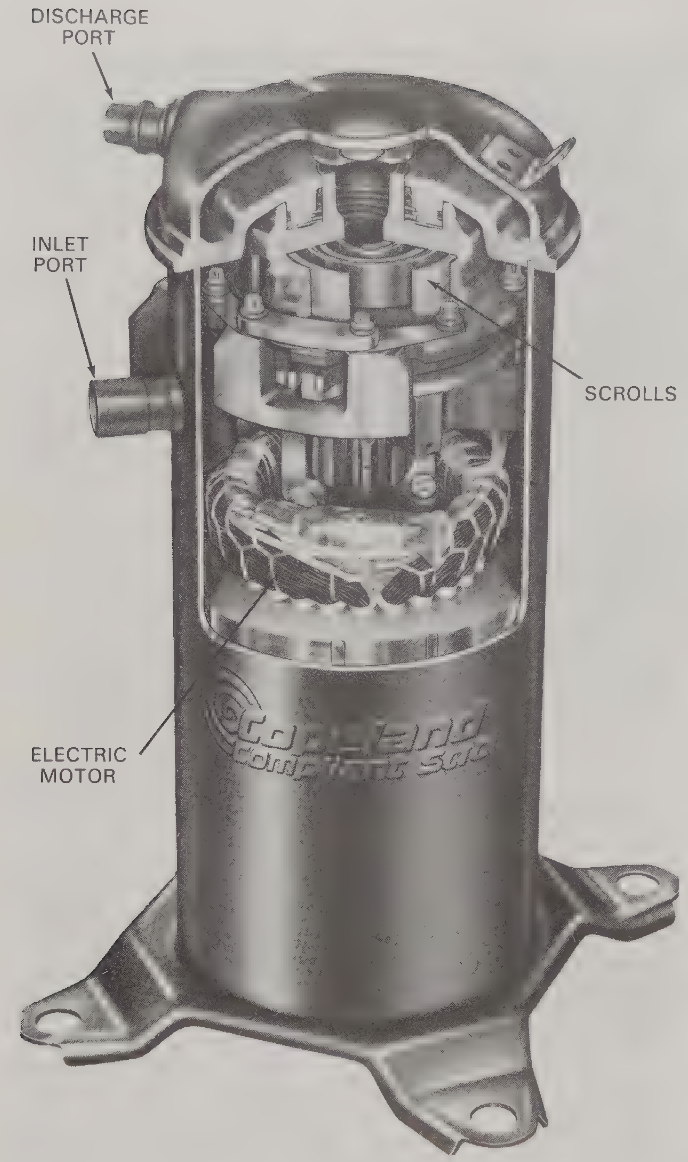


A

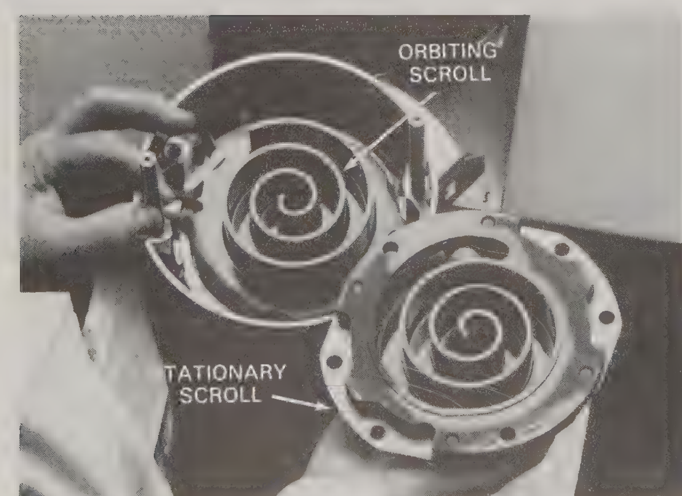


B

Fig. 17-3. Screw-type compressor. A–Cutaway view of typical screw compressor. It has fewer moving parts than a reciprocating compressor and operates more quietly. (Bohn Heat Transfer) B–The matched pair of augers in a screw-type compressor are shown here in end view.



A



B

Fig. 17-5. Scroll compressor. A–Cutaway view of a typical scroll compressor. B–Compressor partly disassembled to show the two scrolls. (Copeland Corp.)

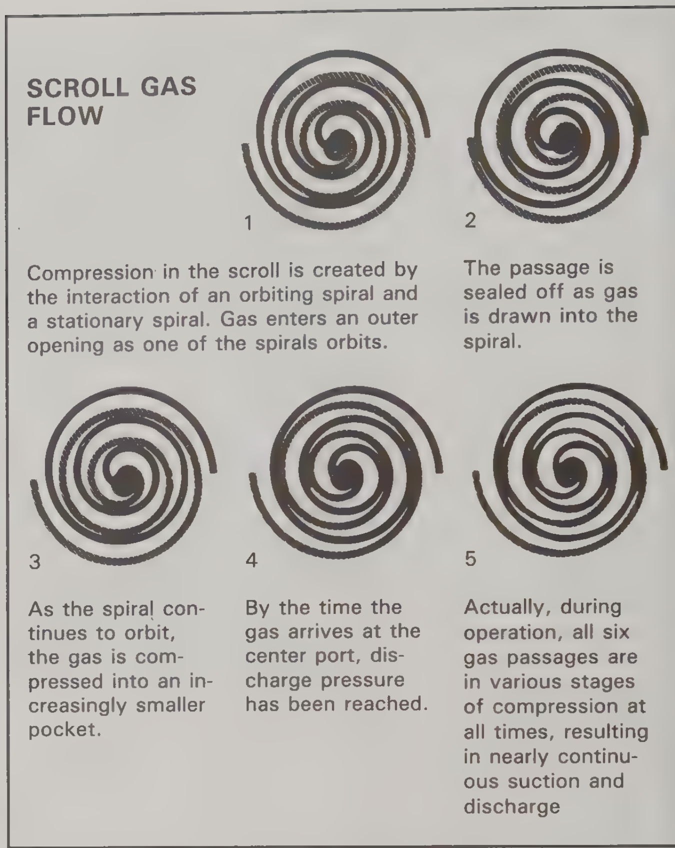


Fig. 17-6. Operation of the scroll compressor. (Copeland Corp.)

while piston-type compressors require a discharge and suction valve for each piston. The scroll compressor is 10 percent more efficient than a reciprocating compressor of the same size, due to elimination of the valves. Scroll compressors eliminate the need for suction accumulators, and crankcase heaters, and can be started under any load without the use of special start kits.

Unlike reciprocating compressors, which can be badly damaged by liquid slugging, scroll compressors have superior tolerance to liquid refrigerant. The scrolls are designed to be ***compliant*** (yielding); they will "give" or separate from each other in the presence of liquid. The pocket of liquid is simply pushed to the discharge opening and the scrolls return to their original position. Compliant scroll compressors also can handle debris (foreign matter) without being damaged.

Compliant scroll technology offers many advantages to meet the needs of air conditioning and heat pump systems. At least seven major manufacturers, both domestic and international, are developing and marketing scroll compressors.

COMPRESSOR DESIGNS

There are three basic compressor designs:

- Open-type (externally driven)
- Hermetic (totally sealed)
- Semi-hermetic (accessible hermetic)

OPEN-TYPE COMPRESSOR

An open-type compressor refers to a compressor that is driven by an external source of power, usually an electric motor. The motor may be direct-connected or may use a V-belt to transmit power to the compressor. See Fig. 17-7.

Open-type compressors are bolted together with the crankshaft extending through the crankcase. A source of power is connected to the external portion of the crankshaft. The most common method is to attach a ***flywheel*** (pulley) to the external crankshaft. An electric motor is connected to the compressor crankshaft pulley by using one or more V-belts. Another, less-common method eliminates pulleys and belts by connecting an electric motor directly to the external crankshaft.

Although open-type compressors represent a small part of the total number of compressors sold today, a great number of them are still operating in commercial refrigeration applications. New open-type designs are still being developed and marketed.

Disadvantages of open-type compressors

The open-type, or external drive, compressors have both advantages and disadvantages. The primary *disadvantage* is the need to provide a leakproof seal where the compressor crankshaft comes through the crankcase. These crankshaft seals are a common source of leaks–it is not unusual to observe traces of leaking oil directly under the crankshaft seal. A small leak is usually ignored, but a larger leak requires field replacement of the crankshaft seal. See Fig. 17-8. The bearings of the

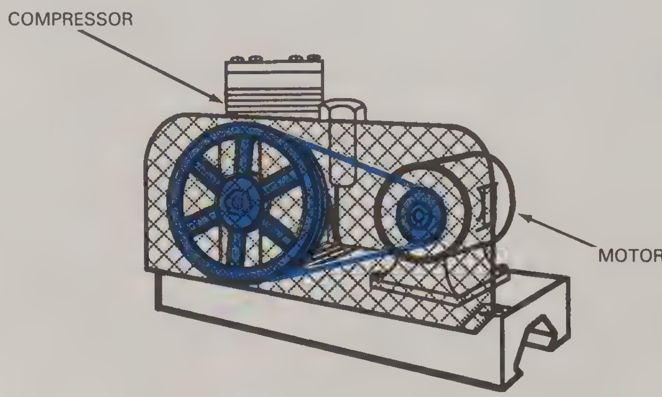
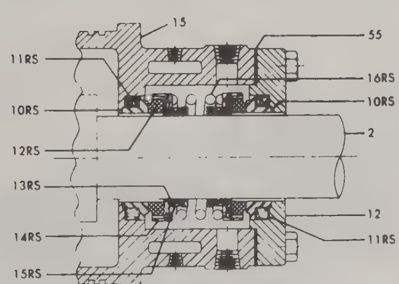


Fig. 17-7. Many open-type compressors are driven by a V-belt connecting a pulley on the crankshaft with a pulley mounted on the motor shaft. A safety guard of metal mesh over the belt and pulleys is normally used.



SEAL PARTS LIST

PART NO.	DESCRIPTION OF PART	
12	SEAL COVER	
15	FRONT BEARING RETAINER (SEAL HOUSING)	
10RS	SEAL SEAT	SEAT SUBASSEMBLY
11RS	SEAL GASKET	
12RS	SEAL FACE	SEAL SUBASSEMBLY
13RS	FRICTION RING	
14RS	RETAINING SHELL	
15RS	FRICTION RING BAND	
16RS	SPRING	
55	SEAL COVER GASKET	
2	ROTOR	

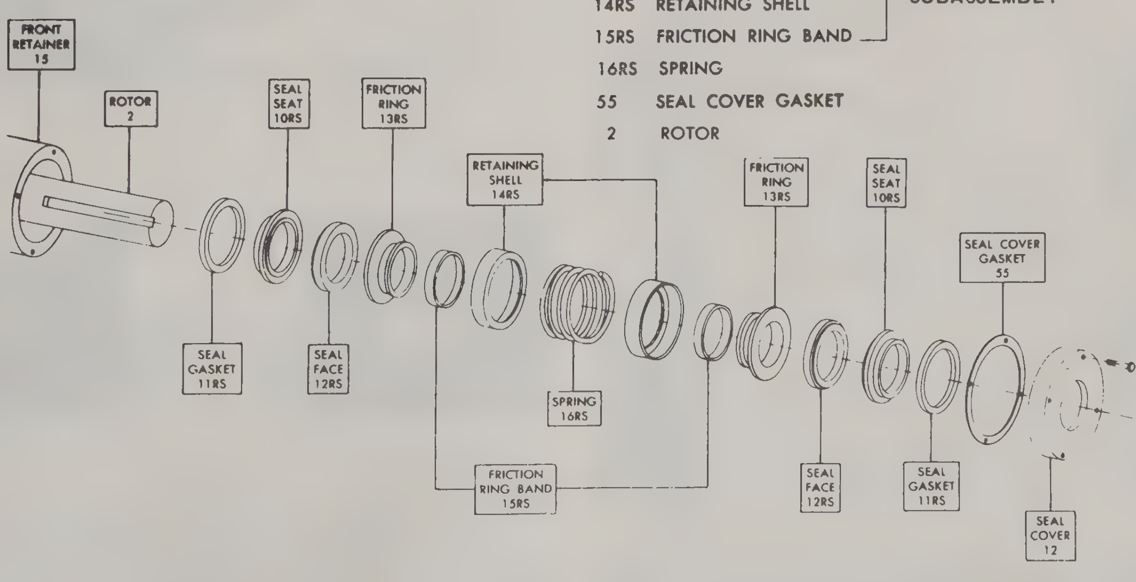


Fig. 17-8. A double shaft seal like this one will prevent leakage when properly installed. (Fuller Co.)

electric motor must be oiled (or greased) about every six months.

To avoid unusual wear and tear of V-belts and to obtain good belt grip, the motor pulley and the compressor flywheel must be properly aligned. Proper alignment of the flywheel and pulley is checked by using a straightedge or a length of string. As shown in Fig. 17-9, both edges of the flywheel and both edges of the pulley must touch the straightedge or string when held in a straight line. Proper alignment is obtained by moving the electric motor to conform with alignment of the flywheel.

To check alignment using a string: Catch one end of a string under the belt near the top of the flywheel, then turn the wheel by hand until the string crosses the rim at the "3 o'clock" position, as shown in Fig. 17-9. Stretch the string across the flywheel and the motor pulley in a straight line. If the flywheel and the pulley are properly aligned, both edges of the flywheel and both edges of the pulley should barely touch the string.

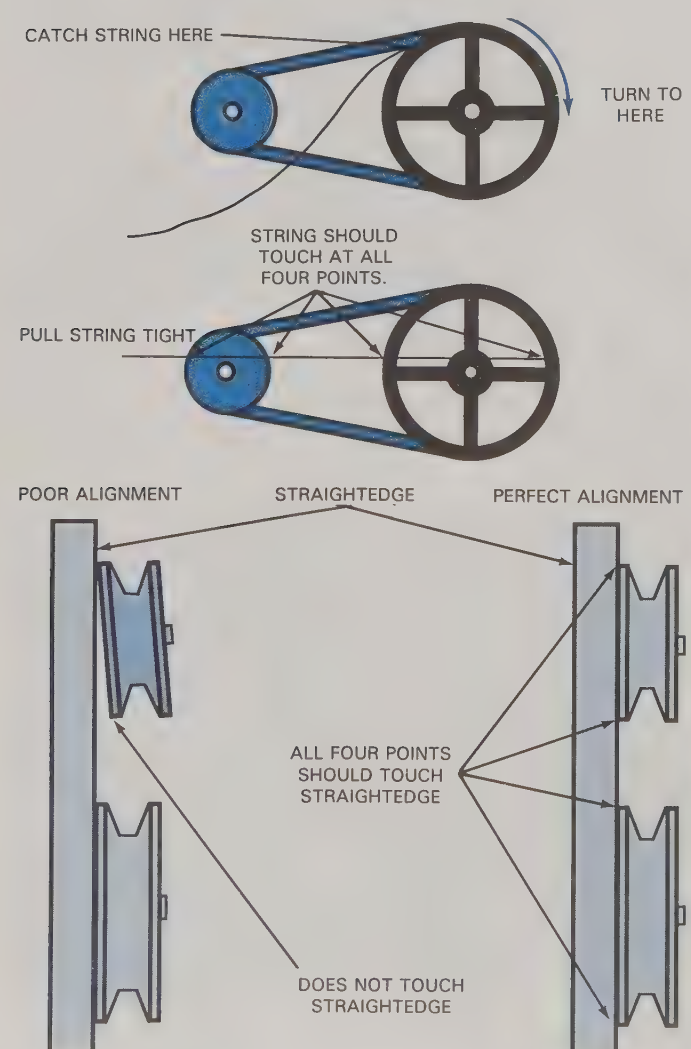


Fig. 17-9. A string or a straightedge can be used to check proper alignment of the flywheel and motor pulley. The string method is shown at top; the straightedge method at bottom.

In the same way, a straightedge can be held against the flywheel and pulley to check alignment, if they are close enough together.

V-belt tension

Proper belt tension is important. V-belts that are too tight cause severe wear of the front motor bearing. Loose belts will slip, squeal, and wear out quickly. Proper tension is measured by using a finger to depress the slack area between the flywheel and the pulley. The belt should deflect about one inch, as shown in Fig. 17-10.

The 42° angle on V-belts, Fig. 17-11A, is designed to give more gripping surface in the pulley V-grooves. It is the *sides* of the belt that provide gripping surface

Fig. 17-10. A properly tensioned V-belt should deflect about one inch when pressure is applied midway between the flywheel and motor pulley.

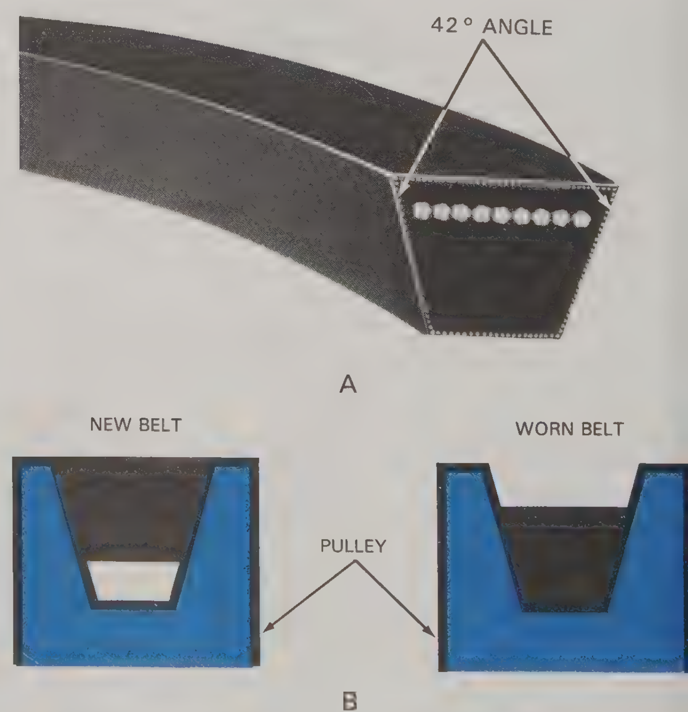


Fig. 17-11. V-belts. A–The sides of the V-belt are sloped at a 42° angle to grip the sides of the pulley groove and transmit power. B–When properly sized, a new belt should be high in the groove, with its top surface flush with the pulley rim. As the belt wears, it slips down into the groove and becomes loose. A worn belt is inefficient and should be replaced.

against the pulley grooves. Some types of belts are also notched on the top or bottom to improve gripping power and fit properly on smaller-diameter pulleys. The top of the belt should ride flush with the top of the pulley, not down in the groove. See Fig. 17-11B. A belt that rides down in the groove is usually loose as a result of wearing down of the belt sides. Check belt width.

When installing V-belts, always place the belt on the motor pulley first. Systems using multiple V-belts require matched belts. Minor differences exist between individual V-belts, but matched belts are identical and will wear evenly.

V-belt sizes. V-belts are available in standard widths of 3L, 4L, and 5L. A 3L belt is 3/8 in. wide, 4L is 1/2 in. wide, and 5L is 5/8 in. wide. The numbers imprinted on each belt indicate the width and length of the belt. See Fig. 17-12A. Thus, a 4L360 belt is 1/2 in. wide and 36 in. long. The ending zero has no meaning, but appears on all belt sizes. A 5L600 belt is 5/8 in. wide and 60 in. long.

Some V-belts are labeled "A" or "B." These are width designations. An "A" belt is equal to a 4L (1/2 in. wide). A "B" belt is equal to a 5L (5/8 in. wide). See Fig. 17-12B. Length numbers follow the A or B designation. All "A" belts are two inches longer than the comparable 4L belt. For example, an A-36 belt is equal to a 4L380. All "B" belts are three inches longer than the comparable 5L belt. For example, a B-55 belt is equal to a 5L580.

Knowing the differences in belt sizes makes it easier to convert from one numbering system to the other. A 4L420 belt is replaced with an A-40. A B-52 belt is replaced with a 5L550.

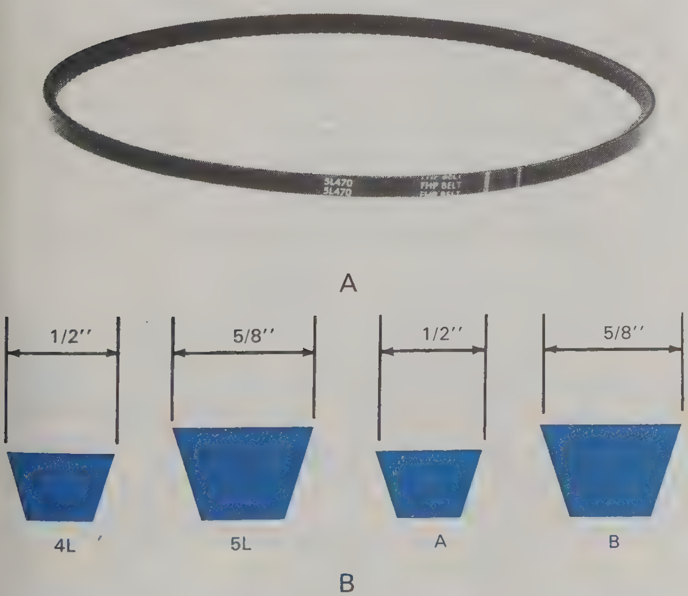


Fig. 17-12. V-belt sizes. A–Belt size is printed on the top for easy reference. The designation 5L470 specifies that this belt has a 5/8'' (5L) width and a length of 47 inches. (Browning) B–Widths of 4L and ''A'' belts are 1/2 in.; 5L and ''B'' belts are 5/8 in.

Advantages of open-type compressors

Open-type compressors can be used with electric motors having odd voltages or frequencies, which is an important factor in foreign markets. Open compressors are always field-serviceable. In case of a motor burnout, the motor is easily replaced.

The primary advantage of open-type compressors is flexibility. Its speed can be changed, allowing a single compressor to be used for units of two or three different horsepower sizes. By changing the size of the motor pulley or flywheel, the speed can be adjusted for use with different-size motors. By changing the speed, the same compressor can be used for high-, medium-, or low-temperature applications.

For belt-driven compressors, speed is determined by the size of the motor pulley, since the flywheel is normally fixed. The speed of the motor and compressor (in *rpm*, or revolutions per minute) are directly related to the diameters of the pulley and flywheel. The following formula is used to solve speed questions:

$$\text{Motor rpm} \times \text{Pulley size} = \text{Compressor rpm} \times \text{Flywheel size}$$

For example, what size motor pulley is needed to provide 500 rpm on a compressor having an 8 in. flywheel? Motor rpm is fixed at 1750 rpm.

$$\begin{aligned} \text{Motor rpm} \times \text{Pulley size} &= \text{Compressor rpm} \times \text{Flywheel size} \\ 1750\text{ rpm} \times \text{Pulley size} &= 500\text{ rpm} \times 8\text{ in.} \\ 1750 \times ? &= 4000 \\ 4000 \div 1750 &= 2.2857 \text{ (Approximately 2-1/4 in. pulley)} \end{aligned}$$

Question: What size pulley is needed to increase compressor rpm to 650?

$$\begin{aligned} \text{Motor rpm} \times \text{Pulley size} &= \text{Compressor rpm} \times \text{Flywheel size} \\ 1750\text{ rpm} \times \text{Pulley size} &= 650\text{ rpm} \times 8\text{ in.} \\ 1750 \times ? &= 5200 \\ 5200 \div 1750 &= 2.9714 \text{ (3 in. pulley)} \end{aligned}$$

HERMETIC COMPRESSOR

The word *hermetic* refers to being airtight, or totally sealed against all external forces. The hermetic compressor unit contains an electric motor that is connected directly to the compressor. The entire assembly is enclosed within a welded steel housing. See Fig. 17-13.

Some advantages of the hermetic compressor are that it is smaller, very compact, almost vibration- and noise-free, has a refrigerant-cooled motor, and has positive lubrication. There is no crankshaft seal and no belts requiring adjustment or replacement.

Since the first welded hermetic compressor was introduced by Tecumseh in 1937, that company has produced over 160 million. Other manufacturers have produced millions more hermetic compressors. Hermetic compressors include many types and styles and

differ widely from each other in appearance, application, and service.

Welded hermetics dominate the residential and light commercial market because of their performance characteristics and high reliability. In size, they range from fractional horsepower units for domestic refrigerators and freezers to 20-horsepower units for commercial air conditioning systems.

Hermetics are engineered to perform a specific air conditioning or refrigeration task. Using hermetic compressors within their design limits will yield favorable results. Asking them to perform outside their design limits will result in poor pumping efficiency and other problems. The key to selecting the right hermetic for a particular job is the evaporator temperature of the system. Each hermetic compressor is designed for a specific evaporator temperature range. Each compressor is also designed for use with a specific refrigerant. Do not substitute. See Fig. 17-14.

Hermetics are not field-serviceable. In the event of a motor burnout, the entire hermetic compressor unit must be replaced. The refrigerant must be recovered from the system, and a filter-drier installed to clean the system of contaminants.

The motor-compressor combination (the motor directly connected to the compressor) is usually used in a vertical position, and is mounted on springs to absorb vibration. A small space exists between the motor-compressor and the housing shell. This interior space is open to refrigerant gas drawn in through the suction line. The gas entering the interior space helps cool the motor-compressor. It also assures oil return to the crankcase.

The factory welds short copper-coated steel ***stubs*** to openings in the housing. See Fig. 17-15. One of these is for brazing of the suction line to the compressor.

Another, smaller opening in the shell is provided with a 1/4 in. or 3/8 in. stub that is called an ***access***

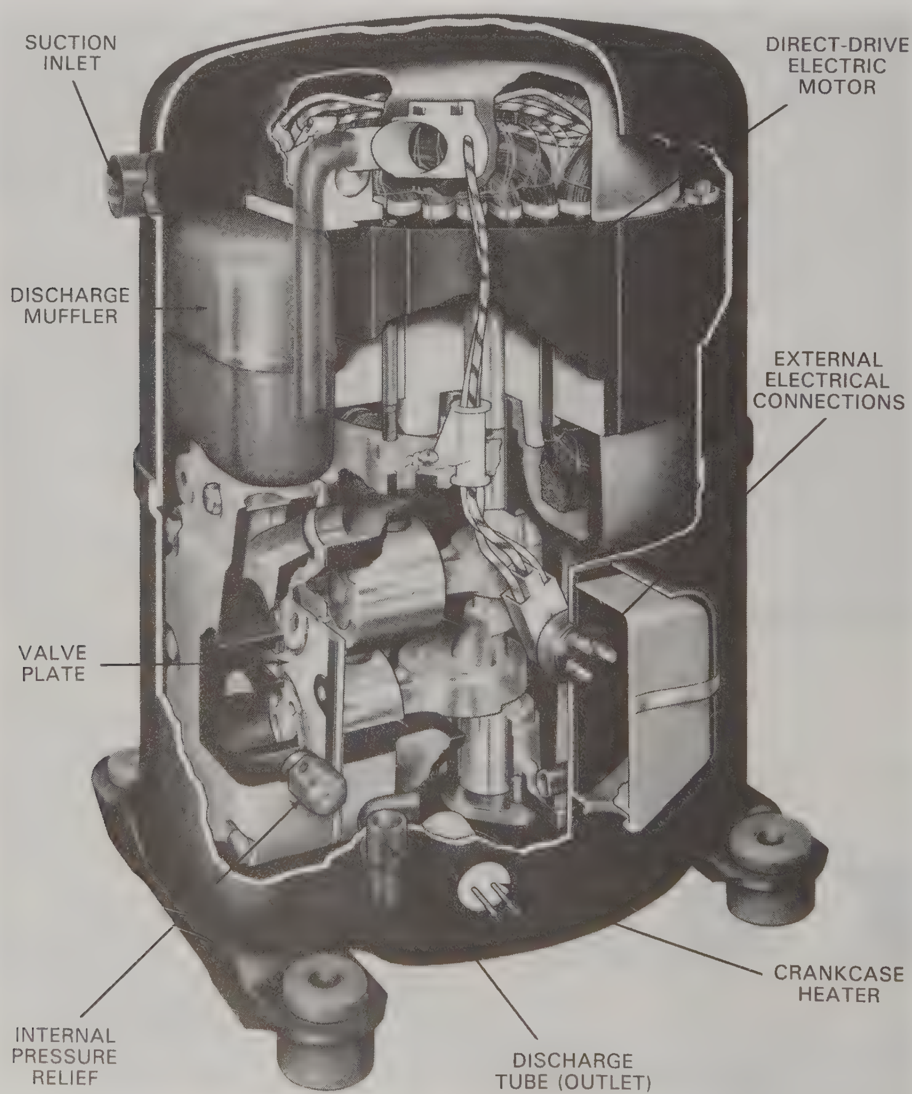


Fig. 17-13. A typical hermetic compressor unit. Since the unit is sealed, it is replaced rather than repaired in the field. (Tecumseh)

HERMETIC COMPRESSOR APPLICATIONS	
APPLICATION	**EVAPORATOR TEMPERATURE**
Air Conditioning	+32 °F to +55 °F (0 °C to +13 °C)
Heat Pump (Approved Models)	–15 °F to +55 °F (–26 °C to +13 °C)
High Evaporator Temperature	+20 °F to +55 °F (–7 °C to +13 °C)
Medium Evaporator Temperature	–10 °F to +30 °F (–23 °C to –1 °C)
Low Evaporator Temperature (Normal Torque Motor)	–30 °F to +10 °F (–34 °C to –12 °C)
Low Evaporator Temperature (High Torque Motor)	–40 °F to +10 °F (–40 °C to –12 °C)

Fig. 17-14. This table presents the evaporator temperature ranges for hermetic compressors used in different applications. A hermetic compressor is designed for use with a specific range of evaporator temperatures.

opening. A Schrader valve is brazed onto the stub for use by the service technician for evacuation and charging procedures during installation. The valve permits easy connection of the low pressure gauge from the gauge manifold. After evacuation and charging are performed, this valve is closed off with a cap nut that has a rubber seal inside. If a valve is not installed on the access stub, the stub must be brazed shut.

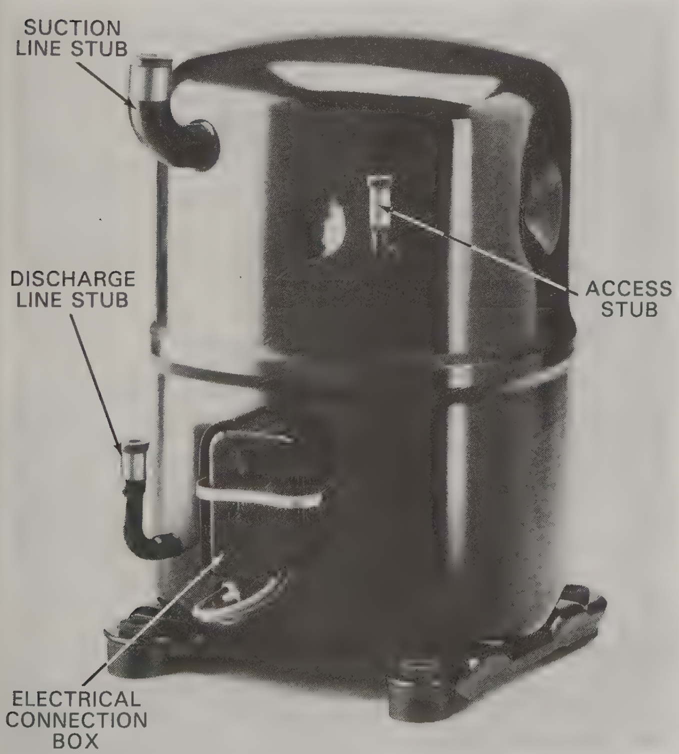


Fig. 17-15. Stubs extend through the welded shell of the hermetic compressor unit to permit necessary connections. The stubs are copper-coated for ease of brazing the connections. (Tecumseh)

The *discharge stub* is welded where it passes through the housing, and is directly connected to the compressor discharge. This procedure prevents the interior suction pressure from mixing with discharge pressure. No provision is made for installing gauges or obtaining access to discharge pressure.

On some low-temperature applications, the hermetic unit will have a special coil of tubing located inside the base (crankcase) of the shell. The ends of this coil extend through the shell as stubs, and are copper-coated. This coil arrangement (which is not open inside the compressor shell), is used to cool the crankcase oil. See Fig. 17-16.

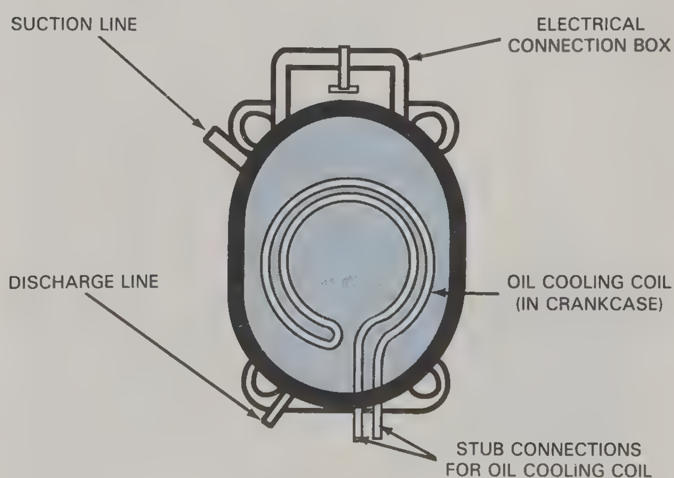


Fig. 17-16. An oil cooling coil is used in the crankcase of some hermetic units to lower the temperature of the compressor oil. The tubing is not open inside the shell, so pressures are separately maintained.

On such low-temperature applications, the hot gas discharge line is run to a small air-cooled condenser (called a pre-cooler). See Fig. 17-17. The temperature of the hot gas is lowered in this small "condenser," but not enough to cause condensation to occur. The warm gas is then run through the oil cooling coil in the bottom of the hermetic compressor. Since the gas is cooler than the oil, the oil gives up heat to the gas. From the exit of the oil cooling coil, the refrigerant gas travels to the normal condenser for actual condensation of refrigerant.

SEMI-HERMETIC MOTOR-COMPRESSOR

The accessible, or *semi-hermetic* motor-compressor design was pioneered by Copeland Corporation and is widely used throughout the industry for light, medium, and heavy commercial systems. See Fig. 17-18. The semi-hermetic type combines all the good features normally associated with the open-type or the hermetic compressor. The crankshaft seal that creates problems in open-type compressors is eliminated, however. The compressor is driven by an electric motor that is mounted directly on the horizontal compressor crankshaft. The working parts of both the motor and the compressor are hermetically sealed within a common enclosure. However, this enclosure is bolted together, and gaskets are used to obtain leakproof seals between the mating parts.

Such a design is compact, economical, efficient, and basically maintenance-free. The removable heads, end bells, and bottom plates allow access for field repairs in the event of compressor damage.

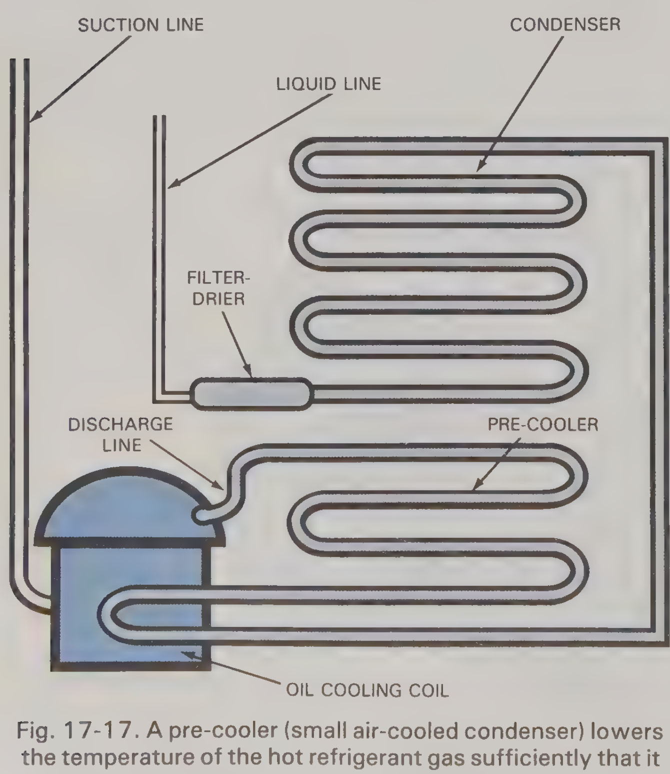


Fig. 17-17. A pre-cooler (small air-cooled condenser) lowers the temperature of the hot refrigerant gas sufficiently that it can, in turn, be used to cool the compressor oil. From the oil cooling coil, refrigerant is piped to the normal condenser.

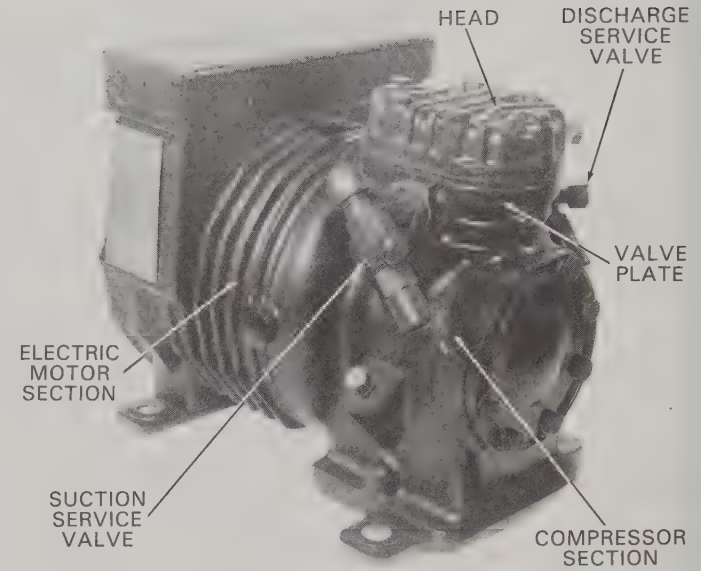


Fig. 17-18. A semi-hermetic compressor. Unlike the welded hermetic type, these motor-compressor units can be serviced in the field. (Copeland Corp.)

These bolted semi-hermetics can be totally disassembled in the field and fitted with new parts as needed. This is a major advantage when dealing with large tonnage machines, where size and weight make total replacement undesirable. In most cases, however, a defective semi-hermetic is simply replaced and *not* repaired in the field. It is not possible to provide enough skilled technicians in the industry to handle the field repair of millions of compressor installations, nor can manufacturers and dealers stock all the parts needed for field repairs. Mass production, standardization, and improved quality have eliminated the need for field repairs in most cases. System reliability and compressor life expectancy has improved to the point where failure rates for these devices are minimal. Occasional repairs are needed to replace a valve plate or an oil pump, but extensive overhaul is seldom required.

Reciprocating compressor operation

Refrigerant vapor enters the compressor through the suction service valve, which is bolted onto an opening in the compressor body. This suction gas is permitted to scatter throughout the compressor body. The suction service valve is often located at the electric motor end-bell to take advantage of the incoming cool suction gas for motor cooling.

Compressor construction

Although variations between manufacturers do exist, the general principles of construction and operation of semi-hermetic motor-compressors are the same. The real difference is in quality, durability, and application.

The semi-hermetic (sometimes called "accessible") motor-compressor was specifically designed for field repairs, if required. Removable heads, valve plates, stator

covers, bottom plates, and housing covers allow repair access in the event of compressor damage. Understanding how these units are constructed is vital to effective troubleshooting and repair work. Accurate diagnosis must be performed *before* removing any bolts. The exploded view in Figure 17-19 illustrates typical compressor construction details. Individual components may vary among models and manufacturers, but the basic method of assembly is similar.

Compressor head

The compressor head is divided into two chambers: one side is suction pressure and the other is discharge pressure. See Fig. 17-20. Openings inside the compressor body create a pathway for suction gas to reach the suction chamber in the head. The compressor head rests on top of the valve plate. The head chamber for discharge pressure is the *only* part of the compressor that is under high pressure. All other parts of the compressor are at low-side pressure.

A special gasket is placed between the head and the valve plate, and another between the valve plate and the compressor body. Capscrews are used to hold these parts together. The bolts extend through the head, gaskets, and valve plate, and screw directly into the compressor body. The capscrews must be tightened slowly and evenly to achieve a leakproof connection.

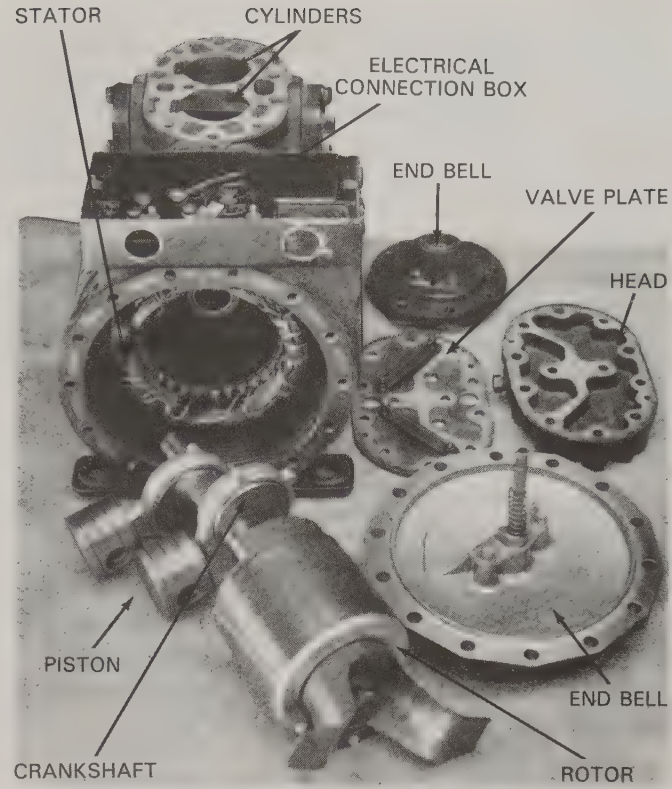


Fig. 17-19. Components of a typical semi-hermetic compressor, which can be disassembled for field service.

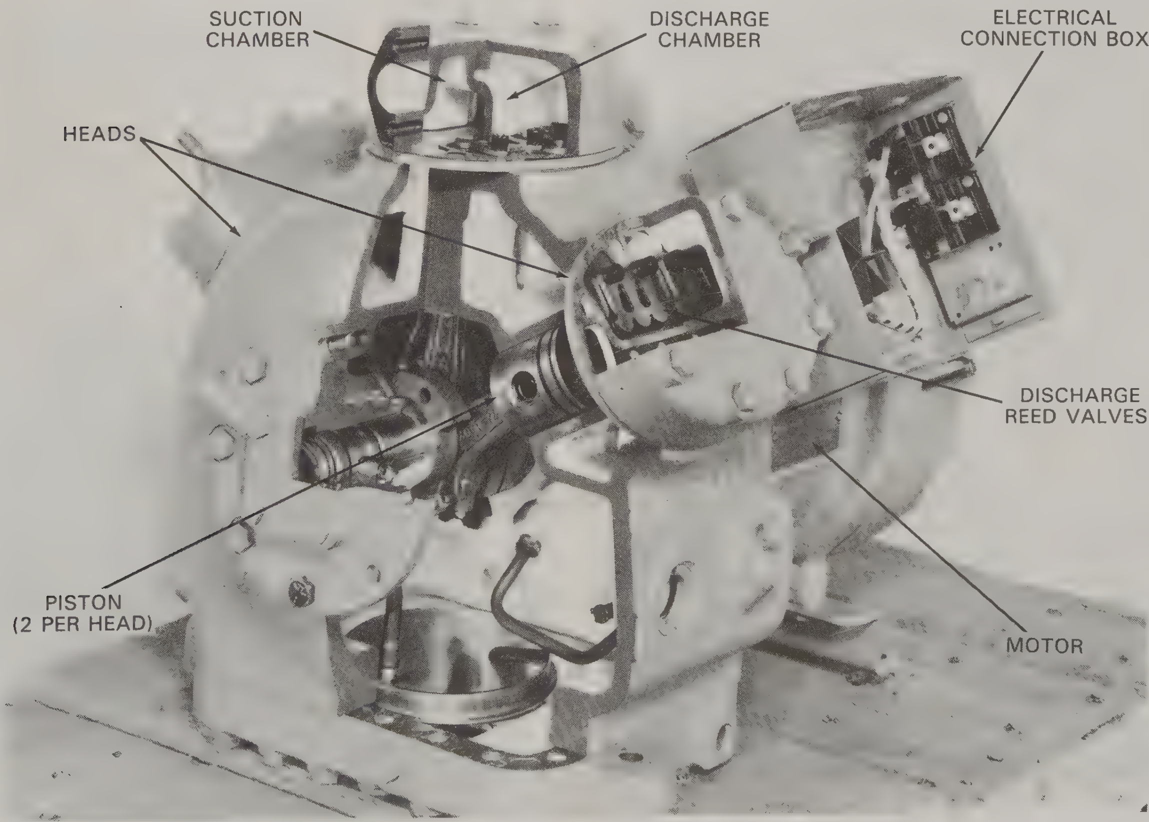


Fig. 17-20. This three-head, six-cylinder compressor cutaway shows the basic construction of a semi-hermetic compressor. The motor is behind the cutaway compressor section, below the electrical connection box. (Carrier)

Compressor valve plate

The *valve plate* is a specially milled steel plate located between the head and the piston cylinders. See Fig. 17-21. The valve plate is a division point between the high-side pressure and low-side pressure. The suction and discharge valve reeds are considered to be part of the valve plate.

Suction valve reed

As shown in Fig. 17-21, the suction *valve reed* consists of a thin piece of steel located on top of the cylinder and under the valve plate. This thin reed is anchored at one end by two steel pins and the valve plate itself. The other end of the reed is permitted to move up and down slightly, due to a small depression cut into the cylinder wall. The piston is not permitted to rise above this small depression (or strike the valve plate), so a ***clearance pocket*** is formed at the top of the stroke. See Fig. 17-22.

The downstroke of the piston causes an area of lowered pressure (vacuum) below the reed. Since pressure of the refrigerant gas in the suction chamber is higher, the end of the reed is pushed down, opening the hole in the valve plate.

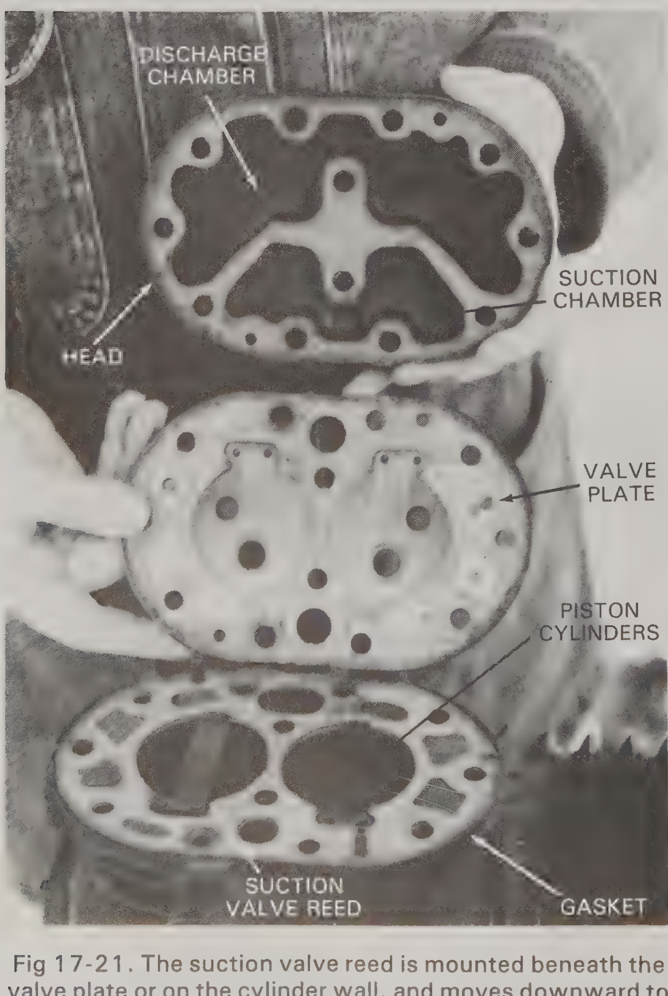


Fig 17-21. The suction valve reed is mounted beneath the valve plate or on the cylinder wall, and moves downward to admit refrigerant gas on the piston downstroke. Gaskets above and below the valve plate provide a tight seal.

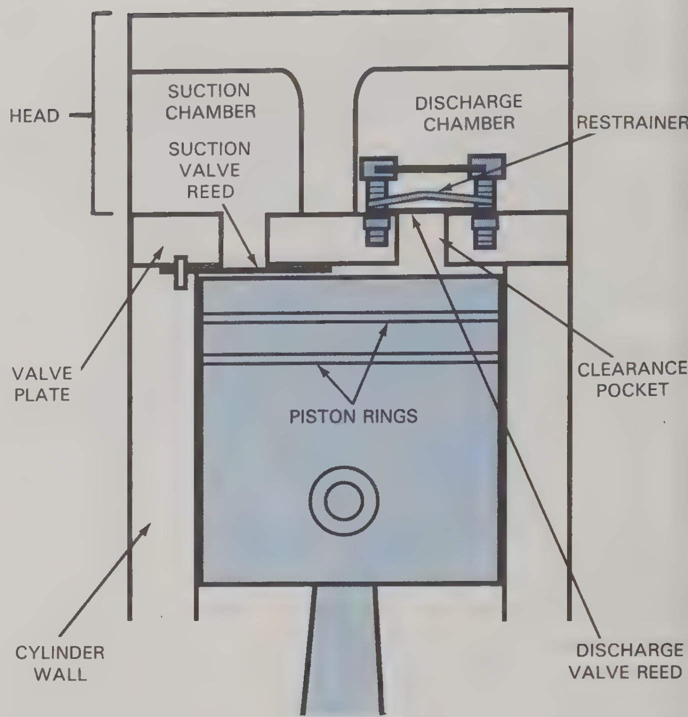


Fig. 17-22. Clearance pocket at top of cylinder avoids contact between the piston and the suction valve reed. Some compressed refrigerant gas remains in the clearance pocket after the discharge reed closes, and is re-expanded as piston moves downward.

Refrigerant vapor flows through the hole in the valve plate, around the suction reed, and fills the cylinder cavity. On the upstroke of the piston, pressure inside the cylinder becomes higher than the pressure in the suction chamber of the head. This presses the suction valve reed firmly against the valve plate hole, trapping the refrigerant gas in the cylinder. Pressure inside the cylinder continues to rise as the piston moves upward, compressing the trapped gas into a smaller volume.

Compressor discharge valve reed

The discharge valve reed is mounted on top of the valve plate, inside the discharge chamber of the head. It covers one or more holes through the valve plate, opening into the cylinder. See Fig. 17-23. High pressure inside the head chamber keeps the discharge valve reed closed. When the increasing cylinder pressure exceeds pressure in the head, the discharge reed is forced open and the compressed gas flows into the head chamber. From the head chamber, the high pressure/high temperature gas travels through the discharge service valve and hot gas discharge line into the condenser.

The discharge reed usually has restrainers that help prevent the reed from bowing too far. These devices protect the discharge valve reed when the compressor is slugging oil or liquid refrigerant.

Each piston cylinder must be equipped with suction and discharge reeds. On larger cylinders, two or more of each may be used.

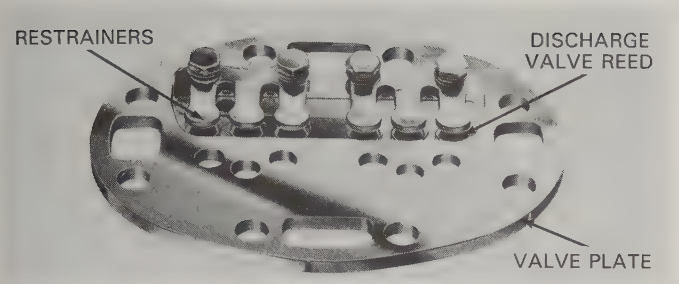


Fig. 17-23. Valve plate with discharge valve reeds and restrainers. The actual valve reed is a thin metal plate held in place by the bolts and restrainers (the thicker metal, three-fingered pieces shown). The restrainers prevent excessive flexing and damage to the reed from liquid slugging. (Carrier)

Disc-type compressor valve

The ***disc-type compressor valve*** was designed by Copeland Corporation and introduced in 1982 under the trade name Discus®. It has been very successful in new commercial refrigeration and air conditioning applications since that time. Other than the new design of the valve plate and head area, the Copeland Discus compressor is a conventional semi-hermetic. See Fig. 17-24.

The disc-type valve design increases compressor capacity up to 25 percent by improving volumetric efficiency. The valve plate in this design virtually eliminates the clearance pocket at the top of the piston stroke, minimizing the re-expansion of gas. This improved volumetric efficiency provides the compressor with more capacity and saves up to 16 percent in operating energy costs.

The Discus valve concept. As shown in Fig. 17-22, ordinary reed-valve compressors have a clearance volume built into the valve plate. High pressure refrigerant gas is trapped in the discharge port area and will re-expand during the piston downstroke. The volumetric efficiency of the compressor depends on the number and size of the discharge ports as well as the compression ratio.

Fig. 17-25 shows the disc-type valve design developed by Copeland. The valve plate is hollow, and serves as a passage for the low-pressure suction gas. Conventional suction valve reeds control the flow of gas into the cylinder. The large discharge port is closed by the valve disc. A disc spring holds the valve disc against the bottom of the discharge port. This minimizes the clearance volume and improves the compressor volumetric efficiency. In addition, disc-valve compressors have domed pistons. This almost eliminates the clearance volume above the piston.

Compressors with disc-type valves are extremely rugged and very dependable, but can be damaged by abuse in the same manner that a reed compressor can be damaged. Proper application and installation procedures must be followed whenever a compressor replacement is made. Do not expect a compressor with disc-type valves to correct system problems.

The Discus design results in increased capacity for a given displacement. When replacing a conventional reed type compressor with a compressor that has disc-type valves, it may be necessary to select a unit with a smaller displacement.

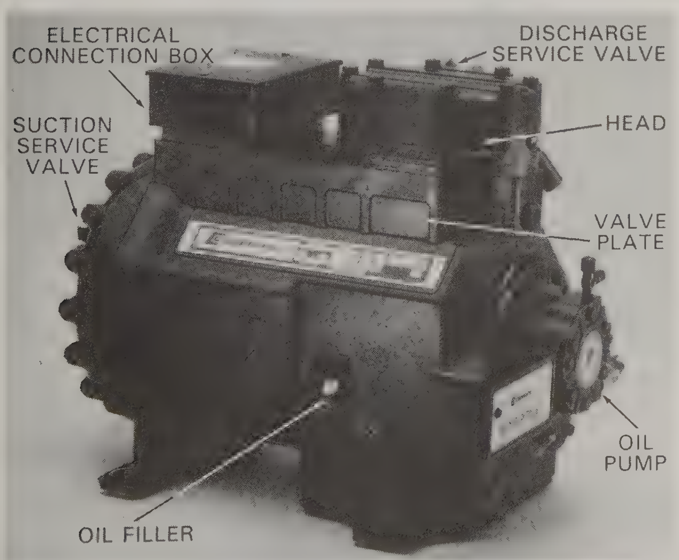


Fig. 17-24. The Discus® compressor is similar in appearance to conventional reed-valve units, but has a radically different valve plate and discharge valve design. (Copeland Corp.)

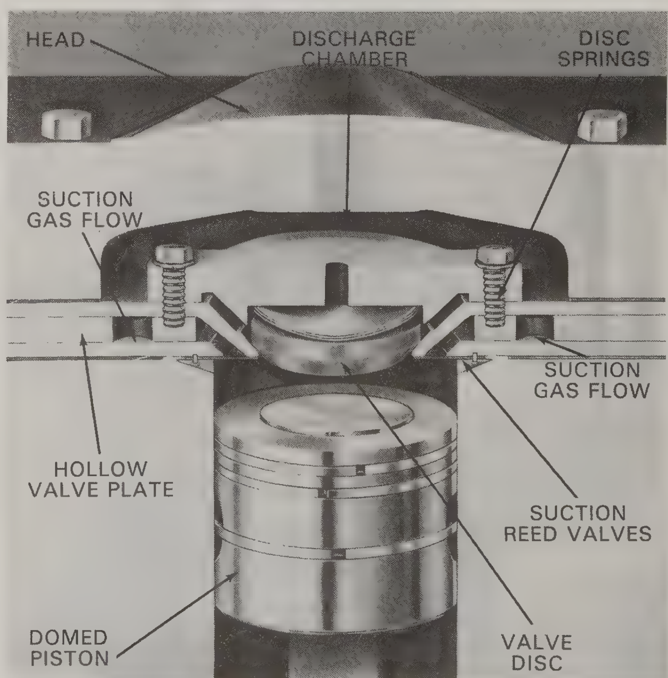


Fig. 17-25. The disc-type valve design is shown in this artist's view. The hollow valve plate provides passage for suction gas and has conventional reed valves for gas flow into the cylinder. The large discharge valve disc is held in place by disc springs. The design improves volumetric efficiency by up to 25 percent. (Copeland Corp.)

Compressor cylinder arrangement

Compressors with one, two, or three pistons will have just one valve plate and one head. Larger compressors with four or more pistons will use two valve plates and have two heads in a "V" arrangement. See Fig. 17-26. Six-cylinder compressors normally have three heads and eight-cylinder compressors have four heads. It does not matter how many cylinders are involved, because the compressors all work in the same way. The only difference is that the larger compressors have more capacity. A four-head V-type compressor will perform the same task as two separate single-head compressors that have the pistons the same size as those on the four-head machine.

Compressor pistons

A *piston* is the device that moves up and down inside the cylinder to compress refrigerant gas. Most pistons are made from cast iron, but the small high-speed hermetic compressor pistons are of die-cast aluminum. ***Piston rings*** are not used on compressors of less than ten horsepower. See Fig. 17-27.

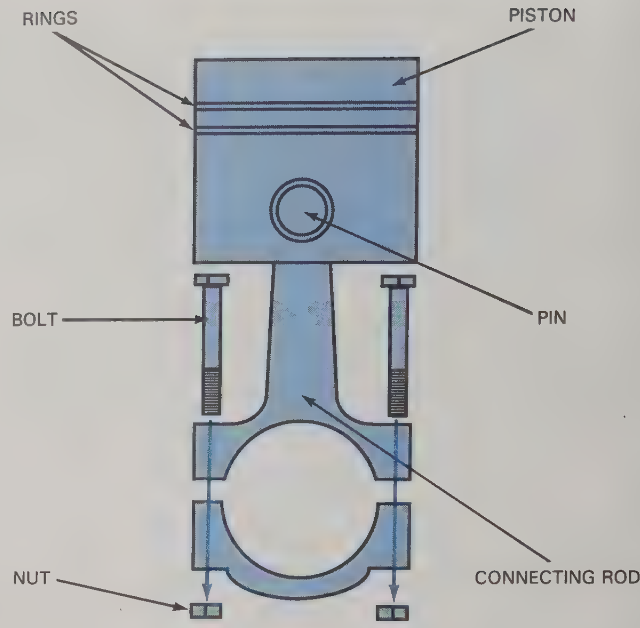


Fig. 17-27. Components of a typical compressor piston assembly. Rings are not used on most smaller-capacity compressors.

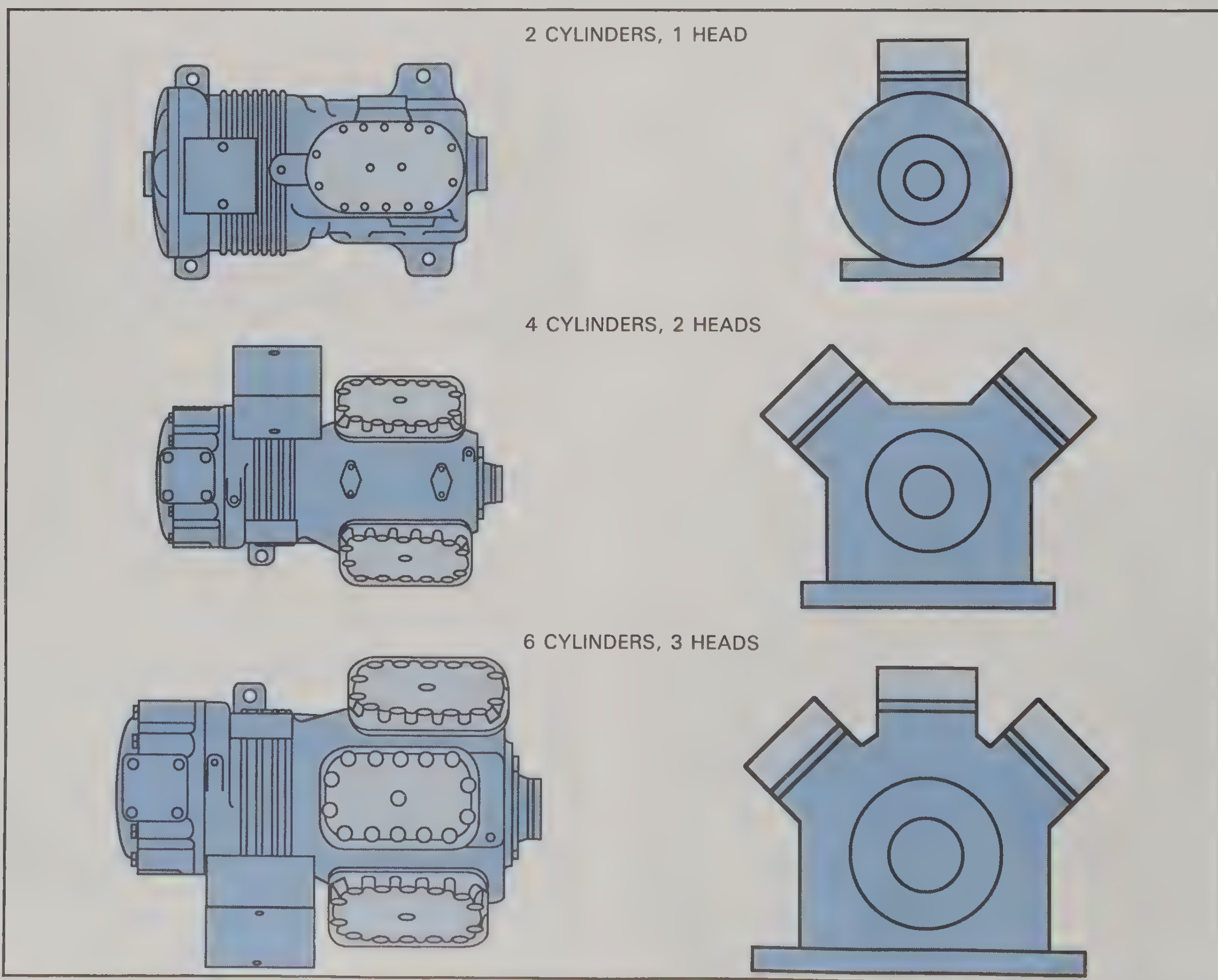


Fig. 17-26. Typical cylinder head arrangements for semi-hermetic compressors are shown in top and end views. Cylinders are usually grouped two per head. (Copeland Corp.)

Fig. 17-28. A crankshaft for a two-cylinder compressor. (Vilter Mfg. Co.)

In a compressor, the temperature of the piston rarely exceeds 250°F (121°C), so expansion of the piston or the cylinder wall is minimal. This permits the pistons to be fitted with as little as .0002 in. (.005 mm) clearance for each inch in diameter. A film of oil will provide the necessary seal between piston and cylinder wall.

A piston pin fastens the piston to the connecting rod. The piston pin is accurately machined and ***full-floating*** (the pin is free to rotate within both the connecting rod and within the piston).

The connecting rod is used to attach the piston to the crankshaft. Connecting rods vary in design, depending upon the type of crankshaft being used. Some are clamped to the crankshaft, while others merely slide over the crankshaft eccentric.

Crankshaft

A ***crankshaft***, Fig. 17-28, is used to change the rotary (circular) motion of the electric motor into a reciprocating (up-and-down) motion. There are various ways to accomplish this purpose, using different crankshaft designs such as the eccentric shaft, crank-throw, or Scotch yoke. Each of these crankshaft designs, however, has the same purpose: to cause the piston to go up and down.

COMPRESSOR MOTOR

On all types of reciprocating compressors, an electric motor is used to turn the crankshaft. Open-type compressors use a separate motor to drive the compressor with a V-belt. The hermetic and semi-hermetic compressors have the electric motor located inside the compressor shell or housing. The rotating part of the motor (the ***rotor***) is fastened directly to the crankshaft. This method is called ***direct drive.***

SUMMARY

The service technician *must* know how compressors work, and also must be able to determine when repair or replacement is necessary. Compressor manufacturers report that many compressors that are returned as defective are victims of a wrong diagnosis: either there is nothing wrong with them, or they failed because of a problem with another system component.

To accurately diagnose compressor problems, the technician must know exactly how the compressor operates. Such knowledge eliminates guesswork and wrong diagnosis. This chapter has explained how each compressor operates to perform its designed task. The reciprocating compressor dominates the industry and, therefore, received special treatment. Later chapters will include further discussion and explanation of compressor malfunctions, lubrication, and electrical characteristics.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name five basic types of compressors.
2. The two types of rotary compressors are the ________ and the ________.
3. The screw compressor has two matched ________.
4. Name the two scrolls used in a scroll compressor.
5. Which type of compressor is not likely to be damaged by liquid slugging or debris in the refrigerant?
6. Name three basic compressor designs.
7. Power for an open-type compressor is normally transmitted by a ________.
8. Which type of compressor is not field-serviceable?
9. True or false? The semi-hermetic compressor has a direct-drive electric motor mounted vertically to the crankshaft.
10. Which compressor type does not have a fixed capacity?
11. What four factors determine compressor capacity?
12. In a reciprocating compressor, what area is under high pressure?
13. The division point between high and low pressure on a reciprocating compressor is the ________.
14. ________ valve reeds are located under the valve plate and ________ valve reeds are above the valve plate.
15. The disc-type valve design increases compressor capacity by up to ________ percent.

Compressor piston and rings. Typically, rings are used only on compressors rated at 10 horsepower or higher. (Vilter Mfg. Co.)

Chapter 18

COMPRESSOR LUBRICATION AND ACCESSORIES

After studying this chapter, you will be able to:
- *Select the proper oil for each system.*
- *Identify the proper oil level in a compressor.*
- *Understand and describe the operation of oil separators.*
- *Add or remove oil from a compressor.*
- *Discuss the factors that can affect compressor capacity.*
- *Describe the means used to control liquid migration in a system.*
- *Identify and install vibration eliminators.*
- *Interpret and use information from compressor data plates.*

NEW WORDS

alkybenzene oils
clearance pocket
compression
compression ratio
crankcase heater
data plates
density
discharge port
eccentric
ester-based synthetic oils
extension
forced-feed system
interstage pressure
lubrication
miscibility
oil passages
oil pressure safety control
oil separator
polyalkaline glycols (PAGs)
radial
retrofitted
slugging
splash system
stable
suction pressure
two-stage compressors
unloaders
vibration eliminators
viscosity
volumetric efficiency

REFRIGERATION OIL

Proper ***lubrication*** is vital to efficient operation and long life of the compressor. *Some* oil normally circulates along with the refrigerant, but precautions must be taken to assure an adequate supply of oil in the compressor at all times. Today's refrigeration oils are primarily a specially refined napthenic group of mineral oils that are very different from the oil used to lubricate automobile engines and other motors.

Requirements for a good refrigeration oil are severe. The oil must provide good lubrication and cool the compressor's moving parts. In a properly operating system, the oil will not decompose, wear out, or need replacement. The oil must be ***stable*** (not break down) and must remain fluid in all parts of the system, even when in direct contact with hot motor windings or discharge valves, or with cold evaporators.

Refrigeration oil is compatible with any system using the common refrigerants. Some systems, however, may require special oil additives to properly lubricate moving parts. Manufacturer's recommendations should be followed in these special situations.

CONTAMINATION

It is important that refrigerant oil be stored in sealed containers. Never leave oil exposed to atmospheric air because it absorbs moisture and other contaminants. Refrigeration oils are available in barrels or in one- or five-gallon containers. Most service companies prefer the one-gallon plastic container, Fig. 18-1, for ease of handling and control of possible contamination.

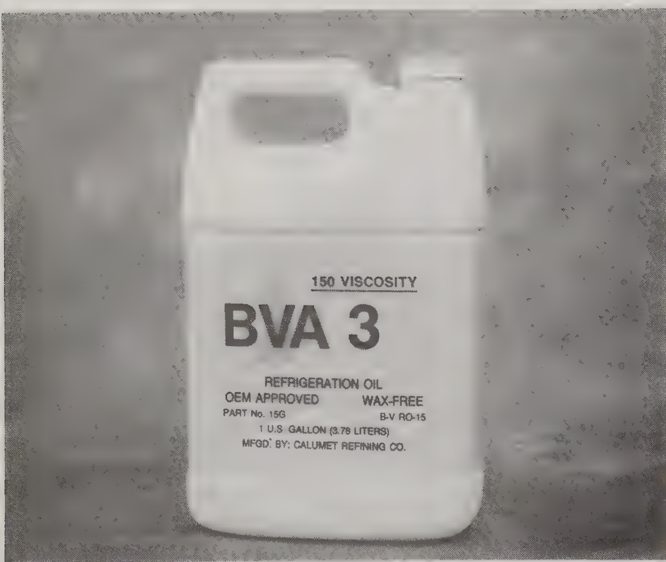


Fig. 18-1. One-gallon containers of refrigeration oil are preferred for ease of handling and storage. They also are less subject to contamination than larger containers with contents that might be only partly used for a given installation. The container shown holds 150 viscosity oil; 300 and 500 viscosity oils are also available. (Calumet Refining Co.)

OIL VISCOSITY

Viscosity refers to the ability of an oil to maintain good lubrication despite temperature changes. Desired oil viscosity must be accurately determined for the temperature range to which the oil is exposed. *Higher* viscosity numbers indicate that an oil will change very little over an extreme range of temperatures. Oils with *lower* viscosity numbers may not flow properly, or may even become a solid, at very low temperatures.

At present, there are three refrigeration oil viscosities available: 150, 300, and 500. When choosing an oil viscosity for a specific application, *always follow the equipment manufacturer's recommendation.* If no recommendation is available, use these guidelines:

- For refrigerants R-11, R-12, and R-113 with evaporating temperatures above -20°F (-29°C), use 150 or 300. Below -20°F, use only 300.
- For refrigerants R-13, R-22, R-114, and R-502, use 300.
- For automotive air conditioning compressors, use 500.

A good refrigeration oil must have these special properties:

- *Low wax content.* Wax separating from the oil will clog valves and capillary tubes.
- *Good thermal stability.* The oil must be able to withstand temperature extremes.
- *Low pour point.* The oil must remain fluid at low temperatures.
- *High dielectric strength.* The oil must be able to resist electrical current flow. (Moisture reduces dielectric strength.)
- *Good miscibility.* The oil must be able to readily mix with refrigerant.

OIL-REFRIGERANT MIXTURE

Refrigeration oils are highly soluble in liquid refrigerant, and at normal room temperatures they will mix completely. This ability of oil to mix with refrigerant is called ***miscibility.*** Oil and refrigerant vapor do not mix as readily, however.

Oil in the refrigeration system is never a pure oil; it is really an oil-refrigerant mixture. The amount of refrigerant dissolved in oil depends upon pressure and temperature in each part of the system. The oil's lubricating ability and viscosity rating is reduced, due to the mixing with refrigerant.

SYNTHETIC OILS

The napthenic groups of refrigerant oils are *not compatible* with most of the new refrigerants that have been developed to lessen the ozone depletion problem. A great deal of research has been done to develop new synthetic oils that are compatible with the new refrigerants. Three of the most popular types of synthetic oils are alkybenzenes, glycols, and esters.

Alkybenzene oils are manufactured from propylene and benzene. The molecule is a *hydrocarbon,* containing hydrogen and carbon atoms. Testing has shown that the new HCFC refrigerants (which are a nearly azeotropic blend of three or more refrigerants) perform much better with alkybenzene oils than with existing napthenic mineral oils. The napthenic oils are not completely soluble in the new refrigerants. The HCFC refrigerants are soluble, however, in a mixture of alkybenzene and napthenic mineral oils with a napthenic oil concentration of 20 percent or less. This means that old refrigeration and air conditioning systems that are being ***retrofitted*** (updated) to use the new refrigerants will not require extensive flushing to rid them of napthenic oil residues.

Polyalkaline glycols (PAGs) were the first synthetic oils developed specifically for use with the new refrigerants, such as HFC-134a. This new refrigerant is chlorine-free and does not harm the ozone layer.

PAG oils have some disadvantages: they attract moisture and are not fully soluble in 134a. They also have poor lubricating ability in aluminum-on-steel situations, an important consideration in compressors with aluminum pistons in steel cylinders. The biggest problem with PAG oils, however, is incompatibility with chlorine. This means that a system formerly charged with R-12 or another CFC cannot be retrofitted. Systems using 134a and PAG oil must be new and charged at the factory.

Ester-based synthetic oils are gaining in popularity, since they are wax-free and have a low pour point and a low floc point. Testing indicates that some ester-based oils are compatible with 134a and a low percentage of mineral oil. This means that retrofit installations are possible with a step-by-step flushing procedure that re-

moves at least 95 percent of the mineral oil from the system.

CONVERTING AN R-12 SYSTEM TO R-134a

Compressor manufacturers have developed a critical, step-by-step procedure for replacing a CFC refrigerant, R-12, with an ozone-safe HFC refrigerant, R-134a. The following brief description summarizes the procedure. Consult with the compressor manufacturer for detailed instructions.

1. Recover all R-12 from the system, using proper equipment and procedures. Before new refrigerant can be installed in the system, the mineral oil lubricant *must* be replaced by a new ester-type oil that is compatible with R-134a. Isolate and remove the compressor from the system and drain all oil from it and other system components.
2. Reinstall the compressor and fill it with new ester-type oil (as recommended by manufacturer). Evacuate the system and refill with the same R-12 refrigerant removed earlier. Run the system for *at least* 48 hours.
3. Repeat step 1. When draining oil, be sure to remove and empty the oil separator, oil reservoir, accumulator, and any other component that might trap oil. Refill the compressor with a fresh supply of the recommended ester-type oil, then evacuate the system and recharge it with the recovered R-12 once again. Run the system for an additional 48 hours. The double change of oil and two periods of operation are needed to be sure most mineral oil residues are eliminated. The maximum concentration of mineral oil in the new oil is 5 percent.
4. Recover the R-12 from the system once more, and again drain all oil from the system. Replace all filter-driers, filters, strainers, and moisture indicators in the system with new components compatible with the ester-type oil and R-134a. Reinstall the compressor and fill it with the proper oil. Thoroughly leak-check the system, then carefully evacuate it to eliminate all traces of air and moisture. Charge the system with the new HFC refrigerant (R-134a) and place it in operation. Observe the system closely for 48 hours, monitoring for high moisture levels. If necessary, replace the filter-driers. After one month, recheck the system to be sure it is operating properly and not leaking.

Oil Additives

Oil additives are sometimes used to provide better performance. Such additives can lower floc and pour points, improve stability, prevent foaming, improve viscosity, and prevent rust. Additives can be combined to provide special properties.

The new refrigerants and new oils have complicated the selection procedure. The old guidelines, using viscosity and temperature to select the proper oil, no longer apply. Mistakes in oil selection can be costly, so it is important to consult the manufacturer's recommendations before adding oil to a system.

COMPRESSOR LUBRICATION

There are basically two lubrication methods used for reciprocating compressors. These two methods are the *splash system* and the *forced-feed (oil pump) system.*

SPLASH SYSTEM

In the ***splash system,*** the crankcase is filled with the correct amount of oil to bring the level up to the bearings. As the crankshaft revolves, the crank throw (***eccentric***) dips into the oil and splashes it around inside the compressor. Small dippers or scoops are sometimes added to help sling oil around to other parts. See Fig. 18-2.

The splash system is most common in small compressors of less than 3 hp. Hermetic compressors for use in

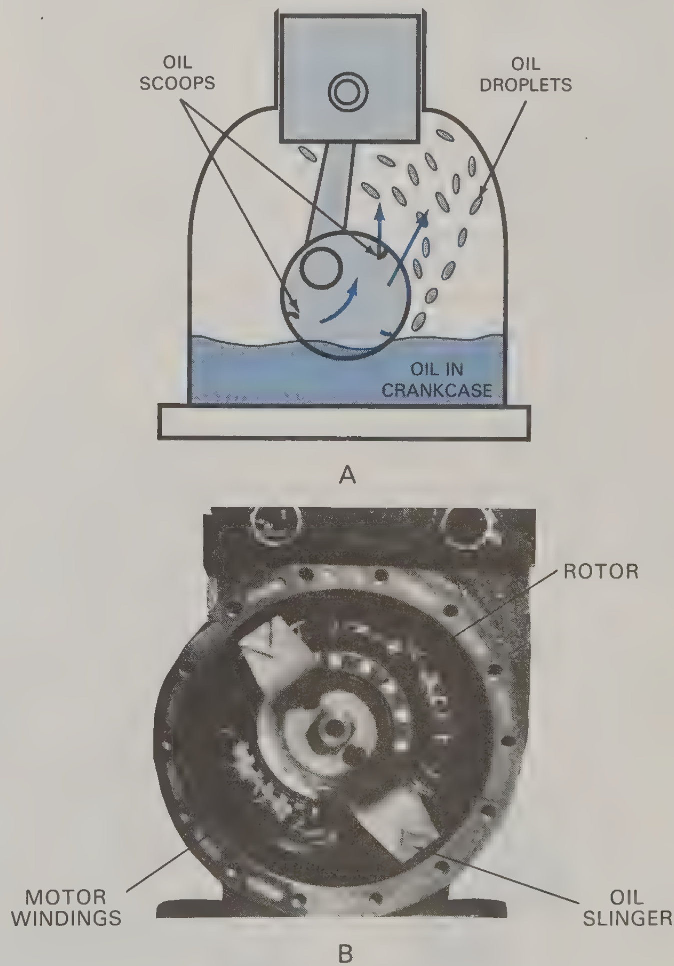


Fig. 18-2. Splash lubrication system. A–Small scoops on the eccentric of the crankshaft splash oil onto compressor parts for lubrication and cooling. B–Oil slingers on the compressor motor shaft splash oil onto the rotor and windings, primarily for cooling. The end bell of the unit has been removed to show the components.

domestic refrigerators, freezers, window air conditioners, and light commercial systems are factory assembled under controlled conditions. Although the amount of oil in these systems is critical, no method is provided to observe or check the oil level. When making repairs to hermetic systems, make every effort to prevent loss of oil. Any oil that is lost should be measured and replaced. If necessary, remaining oil must be removed and a new factory charge installed.

Most welded hermetic compressors are installed in systems without service fittings. Adding oil to a welded hermetic unit usually involves cutting the suction line. This allows the oil to be poured into the compressor. (The suction connection on a welded hermetic opens directly into the shell.)

FORCED-FEED (OIL PUMP) SYSTEM

The *forced-feed system* uses an oil pump to deliver oil, under pressure, to all bearing surfaces and other critical parts. The oil pump delivers oil through special ***oil passages*** drilled in the crankshaft, connecting rods, and other components. With this pressure system, the compressor gets better lubrication, allowing smaller bearing clearances. Oil pumps are usually provided on compressors of 3 hp or more.

The oil pump is normally mounted on the end bell at the crankshaft bearing housing. As shown in Fig. 18-3, the oil pump has a shaft with a flat end that fits into a slot cut into the crankshaft. The oil pump is driven by the turning of the compressor crankshaft.

The pump obtains oil directly from the crankcase and forces it through a hole in the crankshaft to the compressor bearings and connecting rods. The pump has a spring-loaded ball check valve that acts as a pressure-relief device. This valve will allow oil to bypass directly to the crankcase if the oil pressure rises above its setting.

Oil pumps are normally equipped with a Schrader valve that is used to attach the gauge manifold for oil pressure readings, as shown in Fig. 18-4. When checking oil pump pressure, you must also check the suction (crankcase) pressure. Since the oil pump intake is located in the crankcase, and the crankcase is always subjected to low-side pressure, the oil pump inlet pressure equals the low-side pressure. To obtain *actual* oil pump pressure, crankcase pressure must be subtracted from the oil pump outlet pressure.

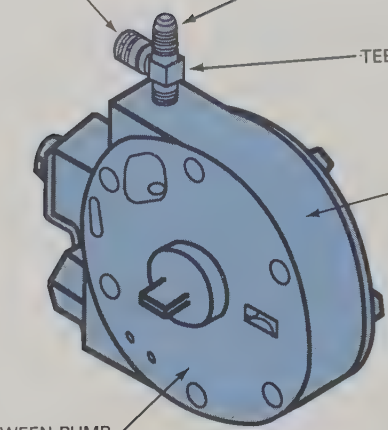


Fig. 18-4. A Schrader valve threaded into a tee fitting permits use of a gauge manifold for reading oil pressure at the pump.

For example, if the crankcase pressure is 60 psig and the oil pump outlet pressure is 100 psig, the net oil pressure is 40 psig.

$$100 - 60 = 40 \text{ psig (net oil pressure)}$$

In normal operation, actual oil pressure will vary depending on compressor size, temperature and viscosity of the oil, and the amount of clearance in the bearings. Acceptable oil pressures will vary from one compressor manufacturer to another, but *minimum* oil pressures are fairly standard. See the Oil Pressure Safety Control heading later in this chapter.

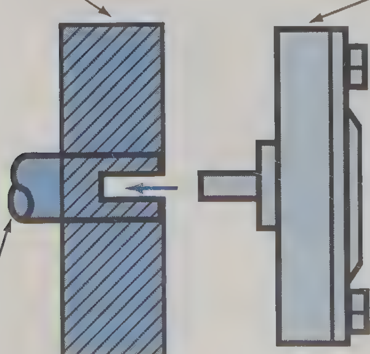


Fig. 18-3. The oil pump is bolted to the end bell of the compressor and driven by the crankshaft.

OIL LEVEL

For proper lubrication, an adequate supply of oil must be maintained in the crankcase at all times. Most semi-hermetic units have an oil sight glass (small window) located on the side of the crankcase for determining oil level in the crankcase. Refer to Fig. 18-6 for typical location of the oil sight glass.

Fig. 18-5 illustrates proper oil levels in the widely used Copeland and Carlyle (Carrier) compressors. In Copeland units, the window should be half-full when the system is running and stabilized. For Carlyle "D" compressors, the oil level is also half-full. For "E" compressors, the oil level should be from 1/8 in. to 3/8 in. up the sight glass. An excessive amount of oil may result in slugging and possible damage to the compressor valves. On field-installed systems, it may be necessary to

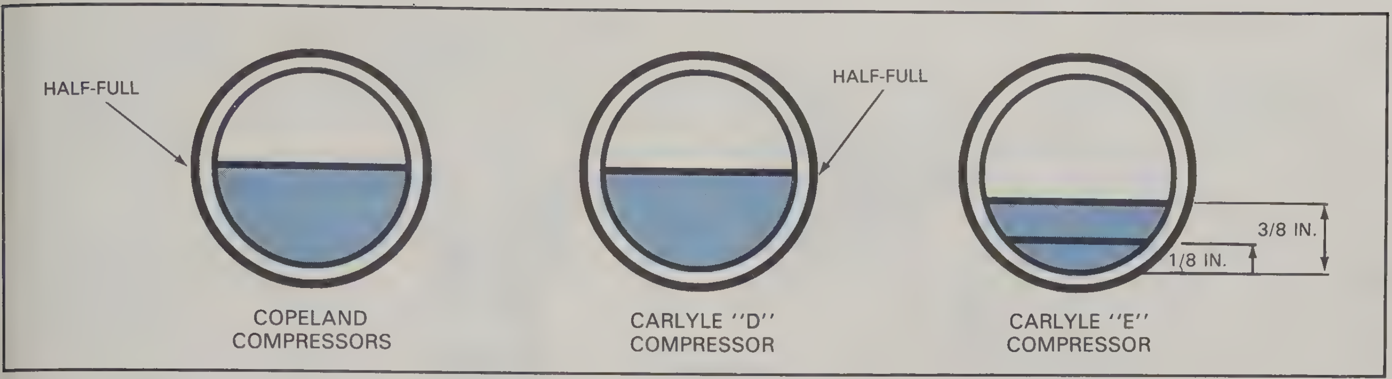


Fig. 18-5. Sight glass oil levels for two popular brands of compressors.

add or remove oil, after the system stabilizes at its normal operating condition, to maintain proper level.

OIL PRESSURE SAFETY CONTROL

A high percentage of all compressor failures is caused by lack of proper lubrication. Lack of lubrication can be due to any of several factors:

- Shortage of oil in the system.
- Improper oil return from the evaporator ("logging").
- Shortage of refrigerant.
- Refrigerant migration or floodback to the crankcase.
- Failure of the oil pump.
- Faulty operation of refrigerant flow controls.

A special oil pressure safety control, Fig. 18-6, is used to protect the compressor against loss of oil pressure. The majority of compressor failures due to loss of lubrication can be prevented by using this control.

Operation of the ***oil pressure safety control*** depends upon the difference in pressure between the oil pump outlet and the crankcase. The top of the control contains a low-pressure bellows (diaphragm). A capillary tube from this bellows is connected to the compressor crankcase, and thus transfers crankcase pressure to the top of the control. The bellows on the *bottom* of the control has a capillary tube that must be attached to the oil pump. This transfers oil pump pressure to the bottom of the control.

If oil pressure falls below safe limits, a switch inside the control will open, stopping the compressor. The compressor cannot restart until the manual reset button on the front of the control is pressed. Oil pressure safety controls have a special time- delay feature. Obtainable with a 30-, 60-, or 120-second delay, this feature helps to avoid nuisance shutdowns because of brief fluctuations in oil pressure during start-up.

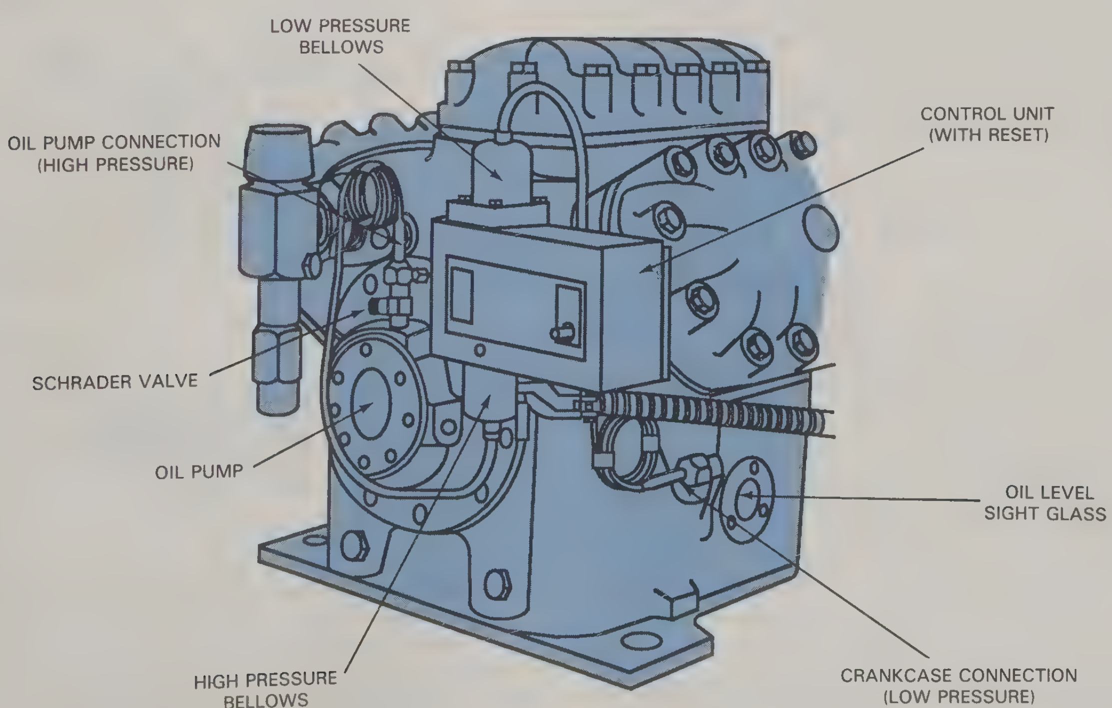


Fig. 18-6. Oil pressure safety control installation on a typical Copeland compressor.

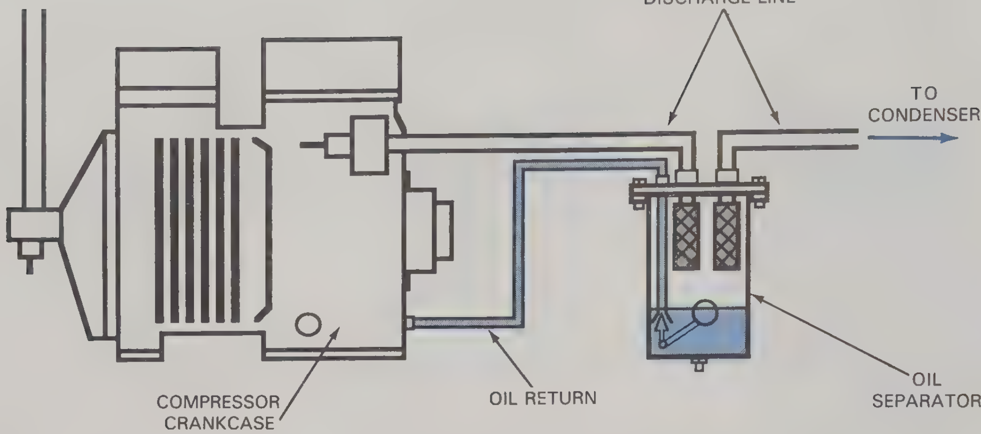


Fig. 18-7. The oil separator is placed between the compressor and condenser to remove oil from the hot gas being discharged from the compressor. The oil is returned to the compressor crankcase.

The delay will prevent a tripout for the specified number of seconds at start-up, regardless of oil pressure. When the time delay expires, net oil pressure *must* be at least 12 psig to 14 psig (83 kPa to 96 kPa) or the control will stop the compressor. During a normal run cycle, the control will prevent net oil pressure from dropping below 9 psig (62 kPa).

Tripping of the oil pressure safety switch is a warning that the system has been without proper lubrication for the time delay period. It is a clear indication that a lubrication problem exists and needs to be corrected. A well-designed system should not trip the oil pressure safety control. Once tripped, the oil pressure safety control cannot be reset until it cools (about two minutes).

Compressor manufacturers often will *require* the use of an oil pressure safety control. Eliminating or bypassing this safety control will void the compressor warranty. Operation of the control and proper wiring to the compressor electrical circuit are fully explained in a later chapter.

OIL SEPARATORS

An ***oil separator*** is used to remove oil from refrigerant and return the oil to the compressor crankcase. The oil separator is installed in the hot gas discharge line between the compressor and condenser, as shown in Fig. 18-7.

When the compressor is operating, some oil is pumped out along with the hot compressed gas. A small amount of oil circulating in the system is normal. The system is designed to provide gas velocities that will sweep circulating oil through the system and back to the compressor. Some low-temperature systems require an oil separator because the density of the refrigerant vapor is not sufficient to sweep oil back. The oil tends to accumulate (log) in the evaporator, condenser, and lines, depriving the crankcase of sufficient oil.

HOW THE OIL SEPARATOR WORKS

Hot discharge gas containing oil in the form of a fog enters the oil separator inlet and passes through the inlet baffling and screens. The baffles and screens force small oil particles to collide and combine into larger, heavier particles. These heavier oil particles drip from the screens to the bottom of the separator, which acts as a sump to collect oil, sludge, and foreign matter. See Fig. 18-8. A

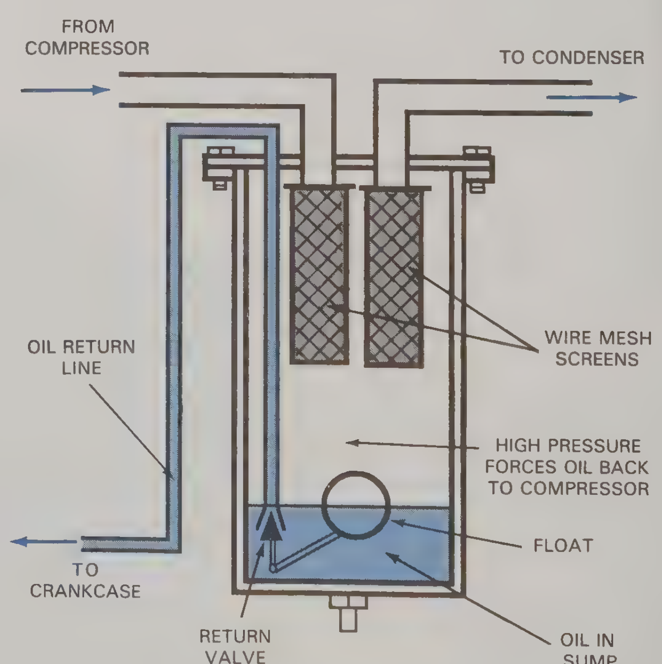


Fig. 18-8. Fine particles of oil in the hot discharge gas collide and combine as the gas passes through the wire mesh screens and baffles of the separator. The larger, heavier drops of oil collect on the screens and drip down to the bottom of the separator. A float opens the return needle valve at a preset oil level, and high gas pressure forces the oil back to the compressor crankcase.

magnet in the sump collects metallic particles and keeps them from being circulated in the system.

Oil will collect in the sump area until the level is high enough to raise a float and open the oil return needle valve. Only a small quantity of oil is required to activate the float mechanism, so only a small percentage of the system's oil is absent from the crankcase at any time. Oil returns quickly to the crankcase because the separator contains high pressure gas that pushes oil back through the return line.

OIL SEPARATOR APPLICATION

Most compressor manufacturers require an oil separator on two-stage compressors, ultra-low temperature systems, and on any system where oil return is critical. A separator is nearly always used on large air conditioning units of up to 150 tons. Overall efficiency of the system is much improved where an oil separator is used. Removing oil from the refrigerant improves efficiency of the circulating refrigerant.

Oil separators should be considered as a system aid, not a cure-all or substitute for good system design. Oil separators are never 100 percent efficient. On systems where piping design promotes oil logging in the evaporator, an oil separator will only delay lubrication-related problems.

If the separator is exposed to low ambient temperatures, it must be insulated to keep refrigerant from condensing in the sump during the off cycle. Liquid refrigerant in the separator would be returned to the compressor crankcase.

ADDING OIL TO A COMPRESSOR

There are three methods that can be used for adding oil to a compressor: the open system method, the oil pump method, and the closed system method. This last method, however, is not recommended, since it can introduce air to the system and can result in slugging that could damage the compressor.

OPEN SYSTEM METHOD

Open-type and semi-hermetic compressors are equipped with a crankcase plug that can be removed to add oil. If the system contains refrigerant, the crankcase is isolated by stopping the compressor, frontseating the suction service valve, and reducing crankcase pressure to about 1 or 2 psig. Remove the crankcase plug and add the required amount of oil, Fig. 18-9.

Refrigerant vapor in the crankcase will produce a slight positive pressure that will prevent entry of air and moisture during the oil-adding procedure. If desired, the crankcase can be purged by cracking the suction service valve off its seat for 1 or 2 seconds. After the oil has been added, replace the crankcase plug, backseat the service valve, and restore the system to operation.

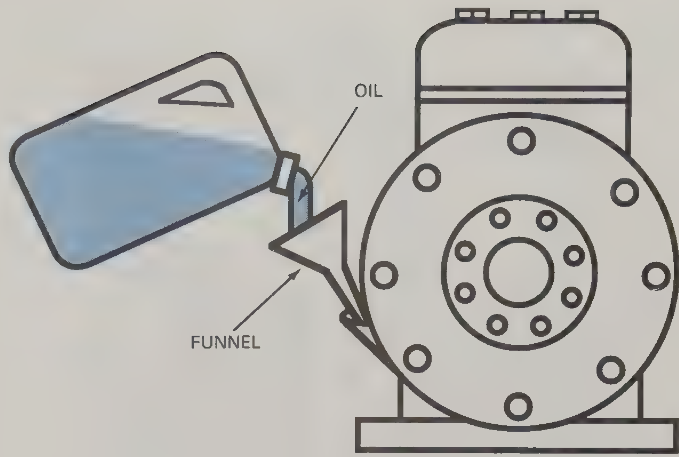


Fig. 18-9. The open-system method of adding oil is used when the system is off. Oil is added through the crankcase fill plug.

OIL PUMP METHOD

Most technicians purchase a small hand-operated oil pump to use for adding oil to compressors. This hand pump, similar to a small bicycle tire pump, is shown in Fig. 18-10. It permits a technician to add oil to an operating compressor through the gauge manifold and suction service valve (SSV), Fig. 18-11. The hand pump contains a check valve to prevent backflow. The pump allows the technician to easily develop sufficient pressure to overcome the operating suction pressure and add oil as needed. Adding oil while the system is *operating* is desirable, because it allows you to observe an accurate oil level via the oil sight glass. An accurate oil level cannot be determined when the system is off.

CLOSED SYSTEM METHOD

Although the method is not recommended, oil may be drawn into the compressor through the suction service

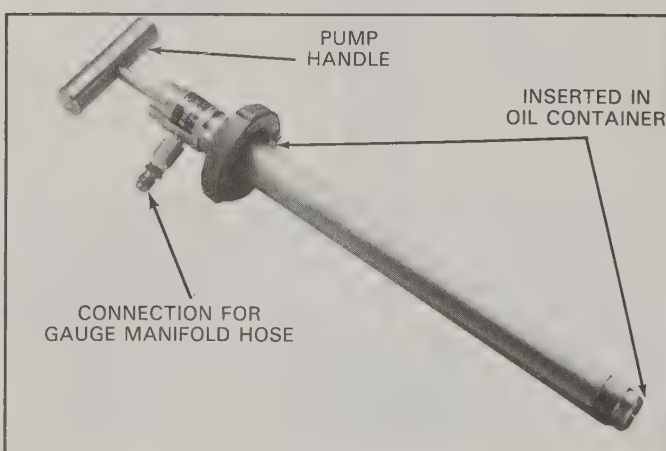


Fig. 18-10. A small hand pump of the type used to add oil to the compressor while the system is running. The pump is connected to the middle hose of the gauge manifold. (Thermal)

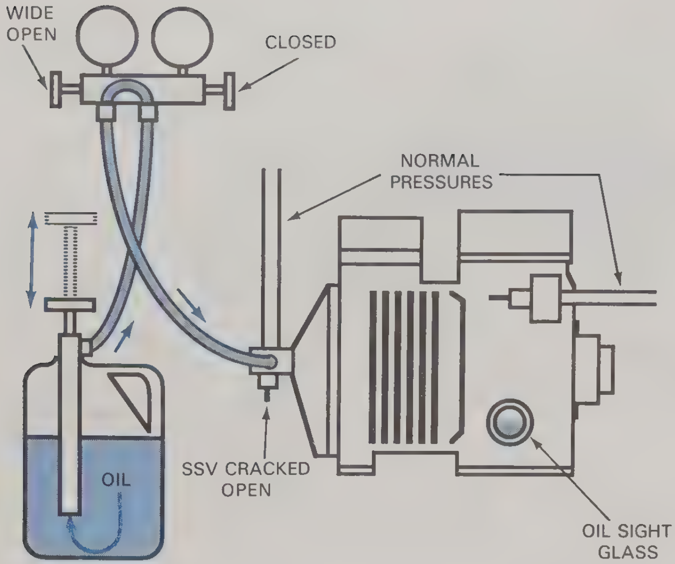


Fig. 18-11. Oil is added while the system is running by using a hand pump connected to the suction service valve through the gauge manifold.

valve by using the gauge manifold. Connect the low-pressure gauge hose (blue) to the SSV and crack the valve open. Crack open the left manifold valve and vent a small amount of refrigerant through the hoses to purge them of air. Submerge the end of the middle charging hose (yellow) in a container of refrigeration oil while venting it. See Fig. 18-12. Close the manifold valve after venting.

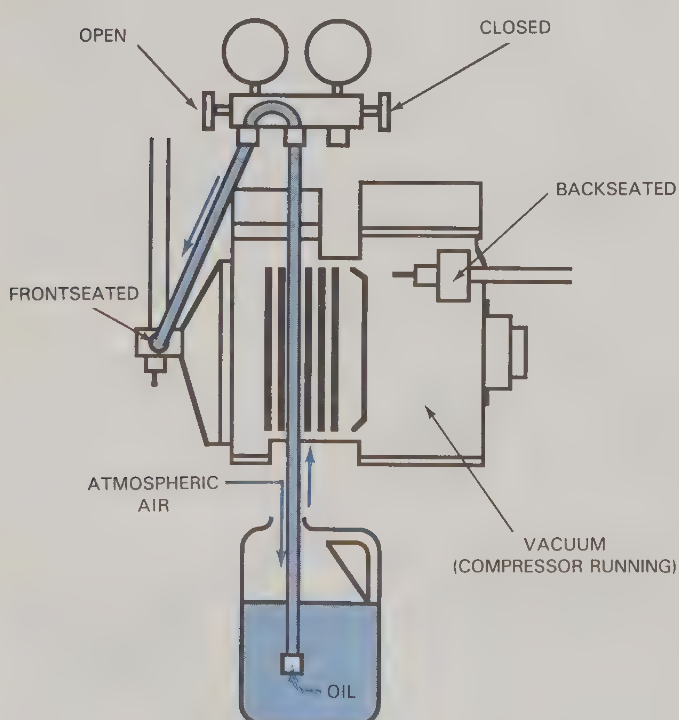


Fig. 18-12. Connections used to add oil to the compressor by the closed system method. This method is not recommended, since there is danger of damaging the compressor or introducing air to the system.

Frontseat the SSV and pull a vacuum in the compressor crankcase by forcing the unit to run. Open the left manifold valve to permit the compressor to draw oil from the container, through the gauge manifold, and into the SSV.

IMPORTANT: Be careful to keep the middle hose end submerged in oil at all times. Otherwise, air will be drawn into the compressor. On smaller compressors, oil must be added very slowly to prevent slugging. Continue adding oil as necessary until the proper amount has been drawn into the compressor.

REMOVING OIL FROM A COMPRESSOR

Sometimes oil must be removed from the compressor due to excess quantity or severe contamination. Most compressors are equipped with a drain plug. Draining is performed with the compressor turned off.

REMOVING EXCESS OIL USING THE DRAIN PLUG

Install a gauge manifold and frontseat the SSV to reduce crankcase pressure to 1 to 2 psig (7 to 14 kPa). Stop the compressor and frontseat the discharge service valve (DSV) to isolate the compressor. Carefully loosen the oil drain plug, but do not completely disengage the threads. Allow pressure to bleed off. Drain oil to desired level by seepage around the threads (do not totally remove the plug). The oil seal at the drain hole and crankcase pressure will prevent entry of air and moisture into the system.

When draining of excess oil is completed, tighten the plug, open service valves, and restore compressor to operation. If the crankcase is totally drained because of oil contamination, tighten the plug and refill with oil using one of the methods described above.

REMOVING EXCESS OIL THROUGH THE OIL FILL HOLE

Install a gauge manifold and reduce crankcase pressure to 1 or 2 psig by frontseating the SSV. Stop the compressor and frontseat DSV to isolate the compressor.

Carefully loosen the oil fill plug and bleed off pressure before threads are completely disengaged. Remove oil fill plug and insert a length of 1/4 in. soft copper tubing so its end is near the bottom of the crankcase. Use tubing that is long enough to permit bending other end down below the crankcase, forming a siphon arrangement as shown in Fig. 18-13. Wrap a clean rag tightly around the copper tubing to seal the oil fill opening. Crack open the SSV slightly to pressurize the crankcase to 4 psig or 5 psig (28 kPa or 34 kPa).

Crankcase pressure will force oil out through the copper tubing and into a container. The oil will continue to drain until the crankcase is empty, if desired. Refrigerant pressure in the crankcase also serves to prevent entry of air and moisture.

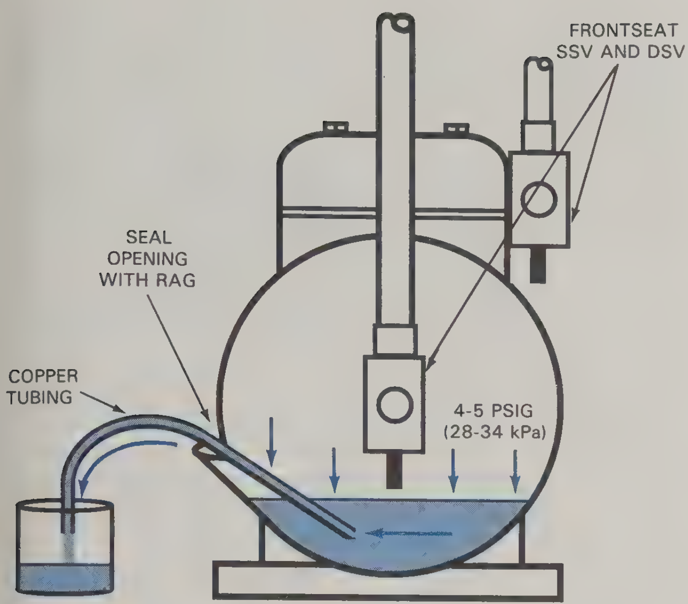


Fig. 18-13. Arrangement used for draining oil from crankcase through the oil filler opening. Sealing the opening around the tubing with a rag will maintain the pressure difference necessary for draining the oil.

When oil removal is completed, remove the copper tubing and quickly reinstall the oil fill plug to prevent loss of refrigerant. Both service valves can be reopened and the compressor restored to operation. If the crankcase was totally drained, refill before operating the compressor by using one of the methods described earlier.

TESTING OIL FOR ACID

When acid is present in a refrigerant system, it is picked up by the oil in the system, which acts as a scavenger. Acid test kits, Fig. 18-14, are available to check the oil for acid contamination. Each kit includes complete instructions for use.

The test is performed by obtaining a small (usually 1/2 oz.) oil sample from the system being tested The oil sample and a test solution are combined in specified amounts in a test tube or similar container, and then thoroughly shaken to mix the ingredients. After the ingredients have been allowed to stand for a few minutes, the color is observed to determine whether acid is present, and in what percentage. The kit instructions contain information on interpreting color changes.

Periodic checks of the oil during a cleanup procedure will indicate when acid contamination has been reduced to a safe level. Cleanup is performed by installing (and changing) acid-removing filter-driers until the test color reveals that the acid level is acceptable.

Carrier Corporation has introduced a kit, called *Totaltest,* that makes possible accurate readings of acid and moisture levels *without* shutting down or opening the system. As shown in Fig. 18-15, the kit consists of an instrument that accepts disposable tubes containing indicator chemicals.

Fig. 18-14. A kit used to test for acid contamination in refrigerant oil. (Sporlan Valve Co.)

The instrument is attached to a service valve or Schrader fitting where a minimum pressure of 60 psig is available. The chemical crystals in the disposable tube react to corrosive acid or any acid-causing moisture that might be present in the system. At the end of ten minutes, the tube is removed from the instrument and the crystal color compared to a chart enclosed in the kit.

DETERMINING COMPRESSOR CAPACITY

The reciprocating compressor is designed as a positive displacement unit, because its capacity depends upon the number and speed of the pistons, and on the volume of the cylinders. Since these compressors are normally driven by an electric motor, the speed is fixed at either 1725 or 3450 rpm (revolutions per minute). Therefore, the amount of refrigerant pumped is calculated by the number of strokes per minute times the total cylinder volume. This means the capacity for any given compressor is limited.

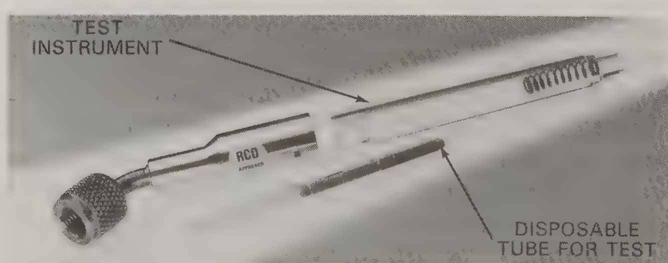


Fig. 18-15. The Totaltest system consists of an instrument that screws onto a service or Schrader valve, and a disposable tube filled with indicator chemicals that fits inside the instrument. (Carrier Corporation)

Compressor capacity is determined by four factors:

- The *diameter* of the piston.
- The *number* of pistons.
- The *length* of stroke.
- The *speed* (strokes per minute).

Capacity plays a very large role in compressor selection for a particular refrigeration system. An oversized compressor (too much capacity) would rapidly remove refrigerant vapor from the evaporator and suction pressure would be too low. Likewise, an undersized compressor (low capacity) would not remove refrigerant from the evaporator fast enough; suction pressure would remain high for a prolonged length of time.

Other factors influencing compressor capacity are the type of refrigerant being pumped and the temperature of the suction gas. The ***density*** of a gas (how closely the molecules are packed) will vary with temperature. A low-temperature gas is "thin", and occupies more space (volume) per pound of refrigerant that a denser high-temperature gas. This means that the compressor piston may be required to make several strokes before it can move one pound of refrigerant. A higher temperature gas is more dense, and thus a pound occupies less space. The same compressor would require fewer piston strokes to move one pound of refrigerant.

The boiling point (***suction pressure***) in the evaporator should be kept high as possible to require the least amount of compressor capacity. As suction pressure goes down, compressor capacity must be increased. Low-temperature compressors require more capacity than medium- or high-temperature applications. For example, R-12 is *not* a good refrigerant for low-temperature applications because suction pressure is very low (possibly in a vacuum) and the gas is too thin, requiring a compressor of high capacity. Using R-502 on low-temperature application would be preferable. It has a higher suction pressure and much thicker gas, permitting use of a compressor of lower capacity.

CLEARANCE POCKET

The volumetric efficiency of a compressor will vary with compressor design. If the valve reeds seat properly, the most important factor affecting compressor efficiency is the ***clearance pocket.*** A clearance space (or pocket) must exist at the top of the piston stroke to prevent the piston from striking the valve plate, Fig. 18-16. Since the discharge valve reed is located on top of the valve plate, the ***discharge port*** (hole through the plate) adds some volume to the clearance space as well. At the top of the piston stroke, the clearance pocket remains filled with hot, compressed gas that does not exit.

As the piston starts downward on the suction stroke, this residue of high pressure gas will re-expand. As it expands, its pressure is reduced. Vapor from the suction line cannot enter the cylinder until the pressure of the re-expanding gas drops below suction pressure.

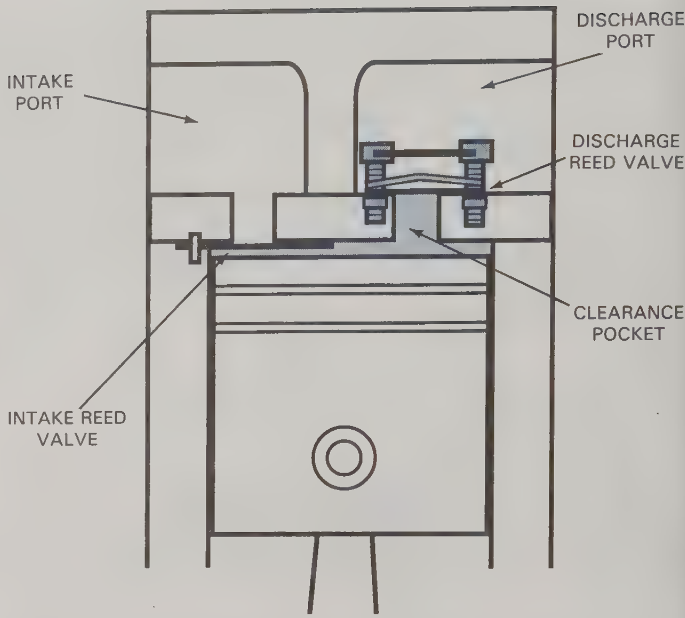


Fig. 18-16. The clearance pocket at the top of the piston stroke affects compressor efficiency. The hot gas remaining in the pocket after the discharge reed valve closes re-expands as the piston moves down on the intake stroke, reducing the volume of new vapor than can be drawn in.

Thus, the first part of the suction stroke is actually lost from a capacity viewpoint. For this reason, the clearance pocket must be kept small as possible to improve volumetric efficiency of the compressor.

On low-temperature applications, it is often necessary to reduce the clearance pocket to obtain desired capacity. Low-temperature valve plates usually have smaller discharge ports.

VOLUMETRIC EFFICIENCY

The ***volumetric efficiency*** of a compressor is a comparison of the amount of gas *actually* pumped by the compressor to the amount of gas it *should* pump, according to piston displacement and length of stroke. This figure is expressed as a percentage. The actual volume pumped (expressed in cubic inches) is divided by the amount of gas the compressor should pump, without any losses. For example, a compressor may be designed to pump 20 cu. in. of vapor per stroke (piston displacement), but actually pumps 12 cu. in. Therefore, volumetric efficiency is 60 percent ($12 \div 20 = .60$).

Compressor manufacturers try to keep volumetric efficiency as high as possible, but field problems can reduce this efficiency.

HIGH HEAD PRESSURE = DECREASED EFFICIENCY

As head pressure increases, efficiency will decrease due to high-pressure gas left in the clearance pocket at the top of the stroke. Also, as suction pressure decreases, the efficiency will decrease, since the pressure

of the gas left in the clearance pocket must be reduced still further to drop below the lower suction pressure. This reduces the amount of incoming suction gas and lowers volumetric efficiency. Every effort should be made to operate the system within its designed capacity.

Compressor efficiency also depends upon the size of ports or openings inside the compressor. Anything reducing the flow of gas through these ports will reduce compressor efficiency.

Each semi-hermetic compressor is designed to be most efficient for a particular evaporator temperature (high, medium, or low) and a particular refrigerant. However, a given compressor may be approved for two operating ranges involving different refrigerants. For example, a compressor may be approved for R-12 at medium temperature, or R-502 at low temperature.

COMPRESSION RATIO

Compression ratio refers to the relationship between the low-side pressure and the high-side pressure. In other words, exactly how much compression is taking place? The compression ratio is figured by dividing the low-side absolute pressure (psia) into the high-side absolute pressure (psia).

Single-stage compressors

The majority of compressors in use today are the single-stage type. The compression ratio for single-stage compressors will go as high as 12:1. If the ratio becomes higher than 12:1, a two-stage compressor is normally used. Lower compression ratios place less demand upon the compressor, which becomes more energy efficient.

Two-stage compressor operation

Because of the high compression ratios needed in ultra-low-temperature applications, ***two-stage compressors*** have been developed. They provide increased efficiency when evaporating temperatures are in the range of -30°F to -80°F (-34°C to -62°C). Fig. 18-17 illustrates a typical two-stage system.

Two-stage compressors are divided internally into low (or first) and high (or second) stages. The three-cylinder models have two cylinders on low stage and one

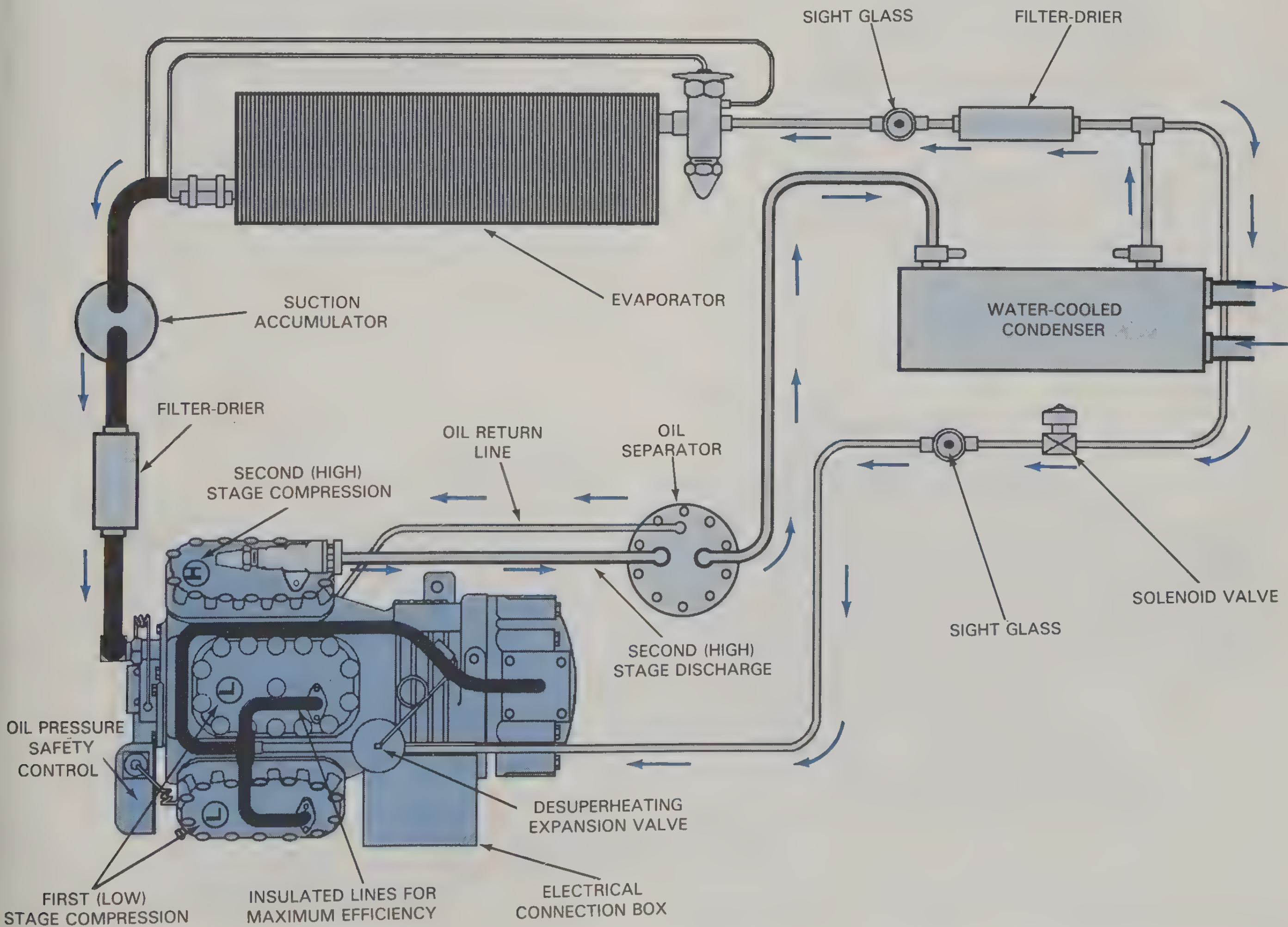


Fig. 18-17. A typical two-stage compressor used for low-temperature systems. Such compressors have high compression ratios and provide increased efficiency.

on high, while the six-cylinder models have four cylinders on low and two on high.

Refrigerant gas enters the low-stage cylinders directly from the suction line, is compressed and then discharged into the interstage manifold at ***interstage pressure.*** This interstage pressure also enters the motor chamber and crankcase, so the crankcase is at interstage pressure, as well.

Interstage discharge gas is at high temperature (highly superheated). Liquid refrigerant is metered into the interstage manifold area by a desuperheating expansion valve (TEV type). The liquid refrigerant immediately boils to desuperheat the discharge gas. This provides motor cooling and prevents excessive temperatures during second-stage compression.

Desuperheated refrigerant vapor at interstage pressure enters the suction ports of the high-stage cylinders, where it is compressed and discharged to the condenser.

Unloaders

Capacity control can be accomplished with unloaders when large compressors must operate at reduced load. ***Unloaders***, Fig. 18-18, are used to reduce compressor capacity. Suction valves on one or more cylinders are held open or closed by mechanical means, in response to reduced suction pressure. With the suction intake blocked off, the cylinder performs no pumping action.

The unloader is controlled by an electric solenoid valve mounted directly on the head and is mechanically connected to the unloader. See Fig. 18-19. Power supply to the solenoid is controlled by a pressure-sensitive switch operating on suction pressure. Fig. 18-20 illustrates refrigerant flow through the unloader in both loaded and unloaded positions.

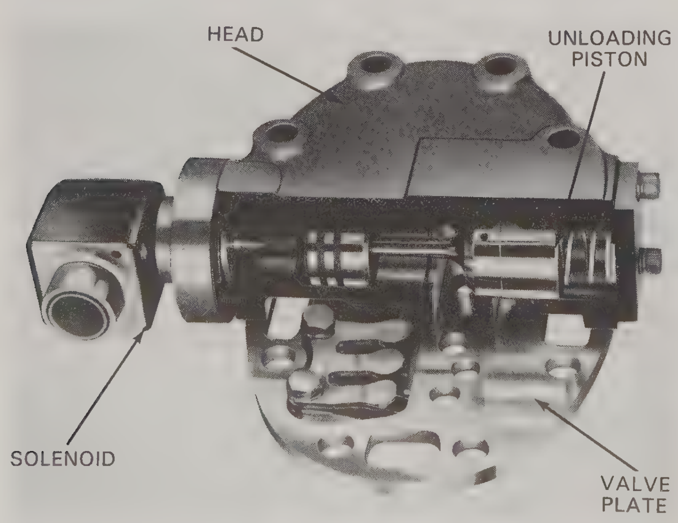


Fig. 18-18. Cutaway view of an unloader. Operation of the solenoid valve controls the unloading piston, which in turn blocks or opens the suction manifold port. This controls capacity by switching the cylinder "on-line" or "off-line," as necessary. (Carrier Corporation)

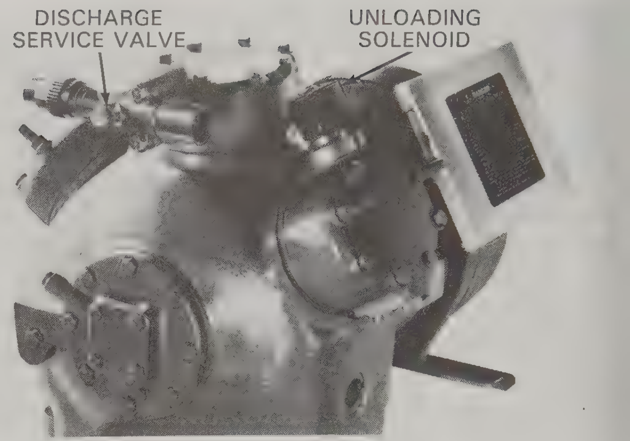


Fig. 18-19. The unloading solenoid is mounted directly on the head of the cylinder it controls. This 6-cylinder compressor has unloading solenoids on two cylinders for capacity control. (Carrier Corporation)

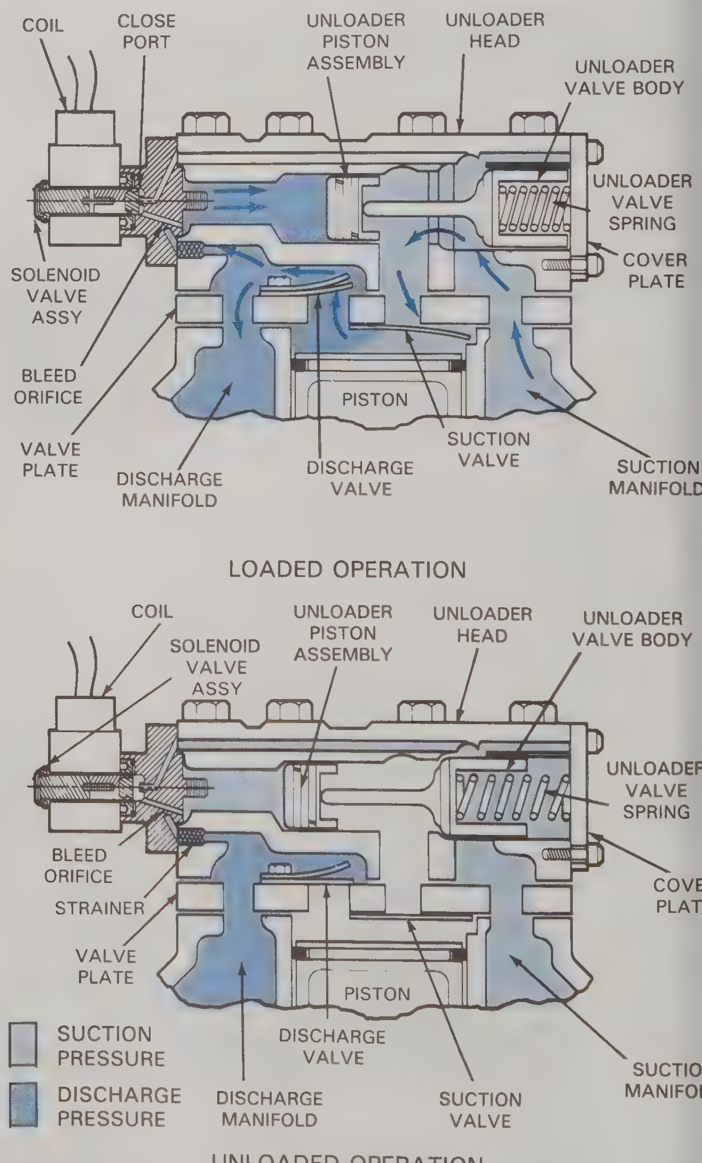


Fig. 18-20. Operation of an unloading system in the loaded and unloaded states. (Carrier Corporation)

Tandem motor-compressors

Sometimes it is desirable to combine two motor-compressors into a single refrigeration system as a means of changing compressor capacity according to reduced load. See Fig. 18-21. Combining of two compressors in this manner presents lubrication problems. Unless the pressures in the two crankcases are constantly equal, oil will leave the crankcase that has the higher pressure.

Tandem compressors were developed to overcome oil and vibration problems and still offer capacity control. The tandem unit consists of two individual compressors with an interconnecting housing that replaces the individual end bells. This permits the compressors to operate individually or together. The tandem offers greater safety factor than a single compressor. If one compressor fails, the remaining one will operate until repairs are completed. Staggered starting reduces electrical requirements. Tandem compressors provide simple, foolproof capacity control with maximum power savings, The tandem arrangement greatly simplifies system control.

COMPRESSOR COOLING

The hot discharge temperatures created at the top of the piston stroke (heat of compression) will greatly affect efficient operation of the compressor. The highly superheated discharge gas temperature is directly related to the temperature of incoming suction gas. Discharge temperatures above 325°F to 350°F (163°C to 177°C) will cause oil breakdown, resulting in sludge and acid. Discharge temperature must be kept below this level. Peak temperatures occur at the discharge valves; the temperature of the discharge line will be from 50°F to 100°F (28°C to 55°C.) *lower* than the temperature at the valve plate. The maximum allowable discharge line temperature is 250°F (121°C), measured six inches from the discharge service valve exit.

The temperature difference between gas at the discharge valve and the discharge line is absorbed by the metal parts of the compressor. This heat cannot be permitted to accumulate, so various methods are used for removing it.

Air cooling

Air-cooled compressors must have a sufficient quantity of air blowing directly on the compressor body to provide motor cooling. Proper cooling can normally be accomplished by locating the compressor directly in the discharge air flow from the condenser fan. If the compressor cannot be located in the condenser discharge air stream, cooling must be provided by another fan discharging air directly against it. See Fig. 18-22. On compressors with multiple heads, a fan is often mounted on top of the compressor with airflow directed downward over the heads, as shown in Fig. 18-23.

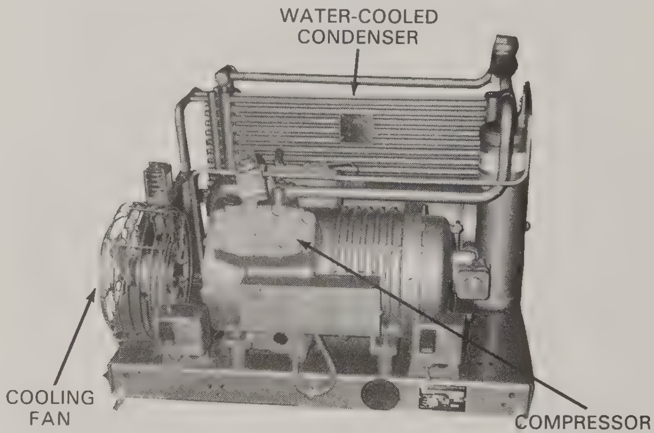


Fig. 18-22. A separate fan blowing air directly onto the compressor provides necessary cooling. (Dunham-Bush)

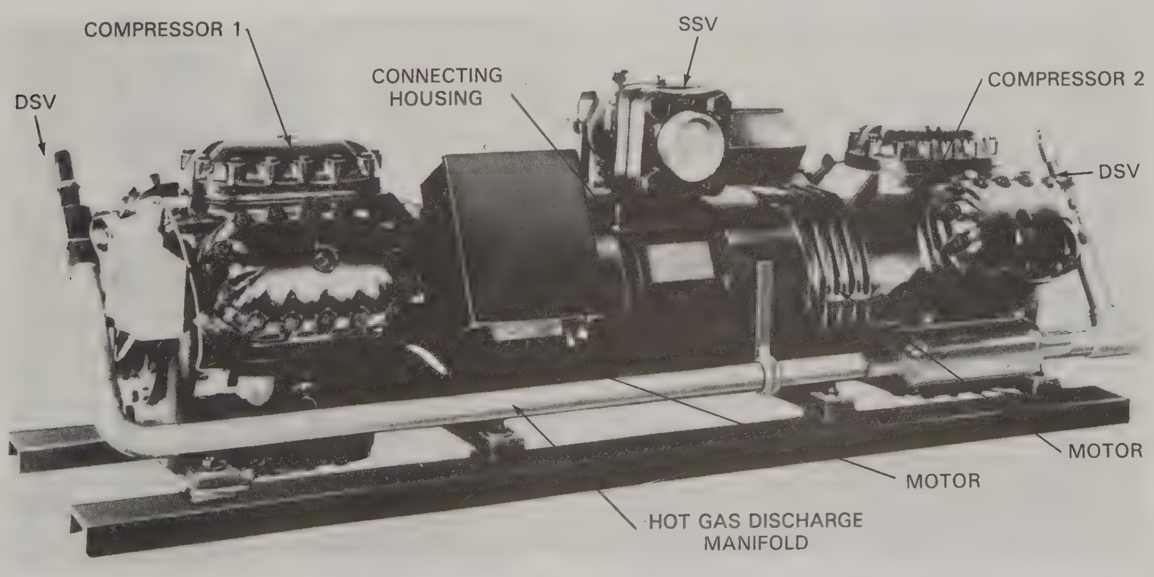


Fig. 18-21. A typical tandem compressor consists of two individual units joined with a connecting housing. (Copeland Corp.)

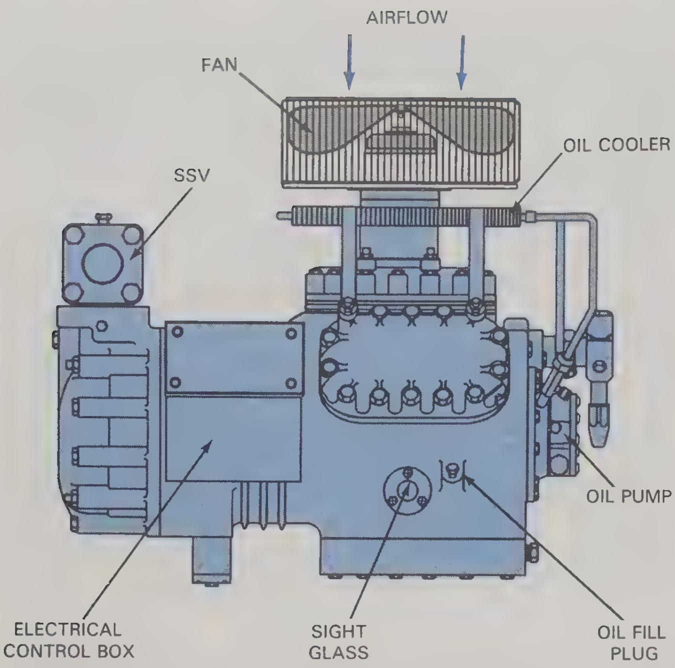


Fig. 18-23. Multiple-head compressors are often cooled by a fan blowing air directly down on the heads.

Refrigerant cooling

Refrigerant-cooled motor-compressors are designed to provide a flow of cool suction gas around and through the motor. At temperatures below 0°F (-18°C), the incoming refrigerant gas is too thin (reduced in density), to provide sufficient cooling ability. Additional motor cooling by means of airflow is usually necessary.

Water cooling

Water-cooled compressors are provided with a special water jacket that permits water to be circulated around the compressor body before going to the condenser. See Fig. 18-24. On smaller compressors, a coil of soft copper tubing is wrapped around the compressor body to act as a water-circulating jacket.

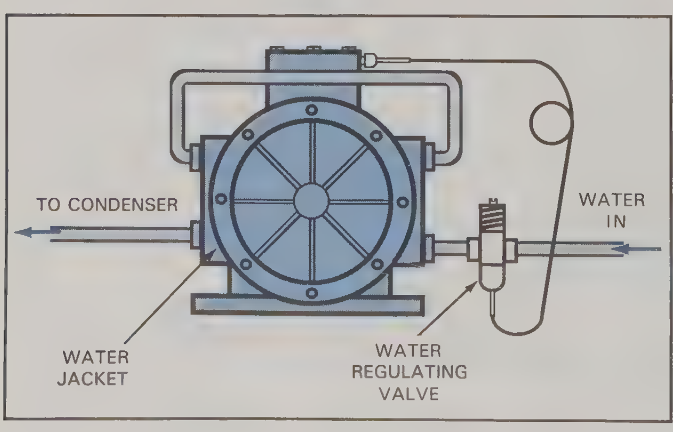


Fig. 18-24. On a water-cooled compressor, cool water circulates through a water jacket that surrounds the compressor body. After exiting the jacket, the water is piped to the condenser to provide further cooling action.

Cooling for equipment rooms

If compressors or condensing units are located in an equipment room, proper ventilation must be provided to control room temperature. Equipment rooms are normally equipped with one or more large exhaust fans that are individually controlled by room thermostats. See Fig. 18-25. As the equipment-room temperature rises, one fan will come on and pull fresh air into the room while exhausting hot air. If room temperature continues to rise, another fan comes on and then another, as necessary, according to settings on the thermostats. Likewise, as the equipment room temperature drops as a result of air cooling, the fans will cycle off and thus maintain the temperature at the desired level. These thermostats are usually set to maintain room temperature at 68°F to 72°F (20°C to 22°C).

CRANKCASE HEATER

A ***crankcase heater*** becomes necessary when the compressor is located in an ambient temperature that may become lower than the evaporating temperature. Due to low ambient temperature conditions, migration of liquid refrigerant (or condensation in the crankcase)

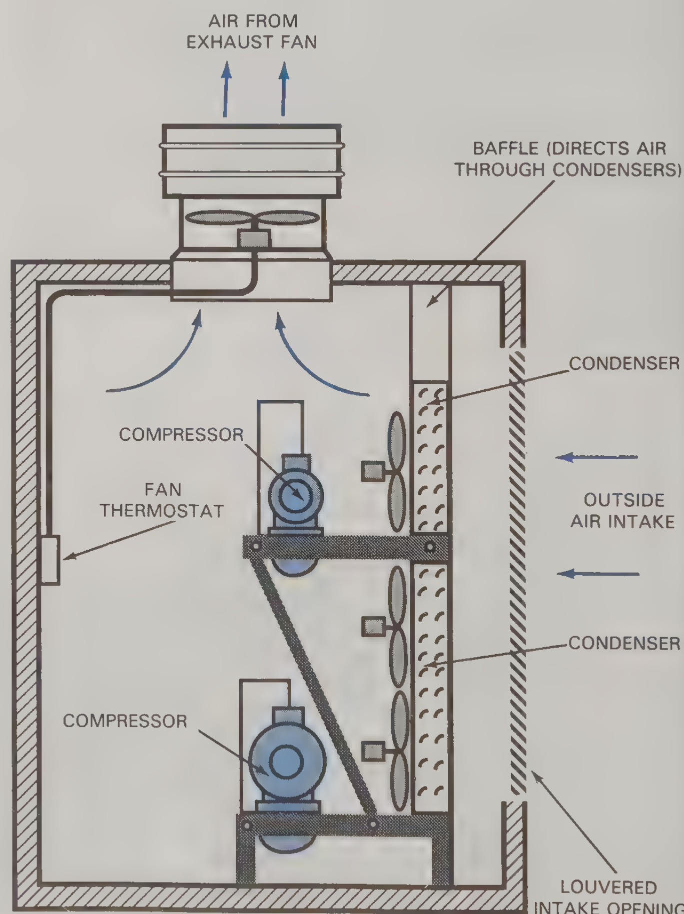


Fig. 18-25. Simplified view of an equipment room cooling system. One or more thermostatically controlled fans cycle on and off to draw outside air through the room and keep room temperature at the desired level.

occurs during the off cycle when the compressor is cold. Electric crankcase heaters are used to keep the crankcase oil warm. Warming the oil helps prevent condensing of refrigerant vapor in the crankcase. Under mild conditions, the crankcase heater will vaporize liquid refrigerant and force it out of the compressor.

Heat always travels toward colder-temperature areas, so if the compressor becomes colder than the evaporator, refrigerant will migrate (travel) to the compressor. Migration is assisted by the pressure difference between the evaporator and compressor crankcase.

Liquid refrigerant in the crankcase will readily mix with oil. Upon start-up, the crankcase pressure is rapidly lowered and some liquid will boil. An oil-and-liquid-refrigerant mixture results and is pulled into the cylinders. This condition is called ***slugging,*** and can cause severe damage to the discharge valve reeds.

Slugging is prevented by eliminating liquid refrigerant in the crankcase. This may require the use of a crankcase heater, suction accumulator, or a pumpdown cycle.

The crankcase heater is often energized continuously (never shut off). Other systems, however, turn the crankcase heater off during the run cycle. An oversized heater may overheat the oil, while an undersized heater will be ineffective. Consult the compressor manufacturer or local dealer to determine the correct crankcase heater type and size. Some heat pumps and air conditioners *require* a crankcase heater to maintain compressor warranty.

COMPRESSOR MOUNTING

The compressor is usually mounted on a set of four mounting bolts equipped with spring and washer assemblies. After installation, the top mounting nut is loosened to allow the compressor to float on the mounting springs. See Fig. 18-26. A space of about 1/16 in. (1.6 mm) between the top nut and the rubber spacer is normal. This method of mounting reduces the transmission of noise and excessive movement during starting or stopping of the compressor. Vibration of the motor-compressor is greatest when it is starting or stopping.

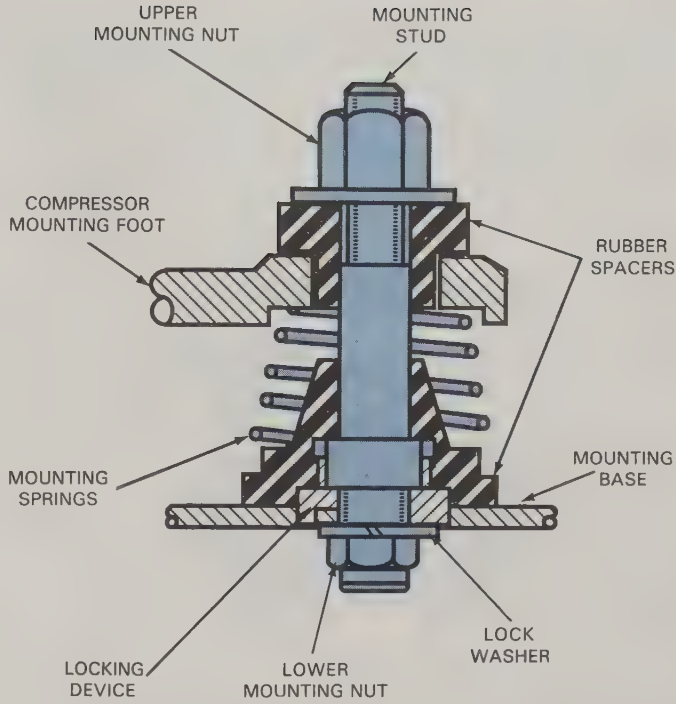


Fig. 18-26. The typical means of mounting a compressor, designed to minimize noise and vibration. Four such mounting assemblies are normally used.

VIBRATION ELIMINATORS

Vibration eliminators are used at the compressor to prevent transmission of noise and vibration to refrigerant piping. Vibration of the piping is a problem, since it will cause leaks to occur. Vibration eliminators are installed close to the compressor in both the suction and discharge lines. See Fig. 18-27. On small units, the soft copper tubing is wrapped in a coil at the compressor to provide vibration protection.

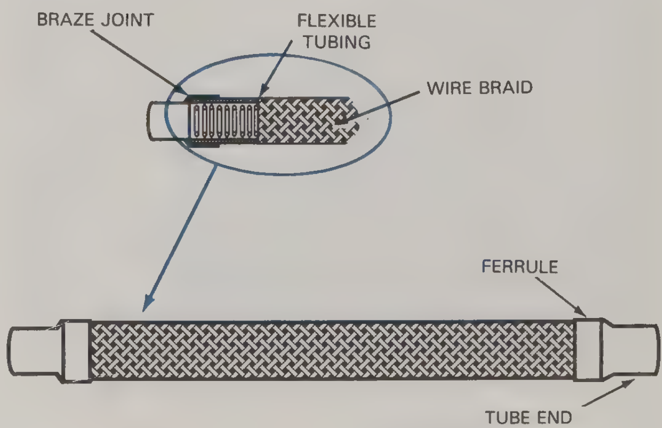


Fig. 18-27. Vibration eliminators made from flexible tubing are brazed into the suction and discharge lines at the compressor. Vibration of tubing can cause joints to leak.

INSTALLING VIBRATION ELIMINATORS

Unless the vibration eliminator is properly installed, stress will cause it to fail or defeat its purpose. The metallic vibration eliminator is designed to adjust to movement in a ***radial*** (circular) direction. It must not be subjected to stress that causes ***compression*** or ***extension*** (push or pull). It is recommended that vibration eliminators be installed as close to the compressor as possible, parallel to the crankshaft. See Fig. 18-28. The starting torque (turning power) of the motor will tend to rock the compressor from side to side when starting. Parallel mounting to the crankshaft allows the vibration eliminators to easily adjust to this movement.

Internal connections of the metallic vibration absorbers are made with a brazing compound that has a melting point of about 1300°F (704°C). To prevent damage to these internal joints, line connections should be made

with a silver alloy having a melting temperature below 1200°F (649°C). Wrapping a wet rag around the vibration absorber before brazing is recommended. Brazing should be accomplished quickly. Overheating may cause damage to the internal brazed connections.

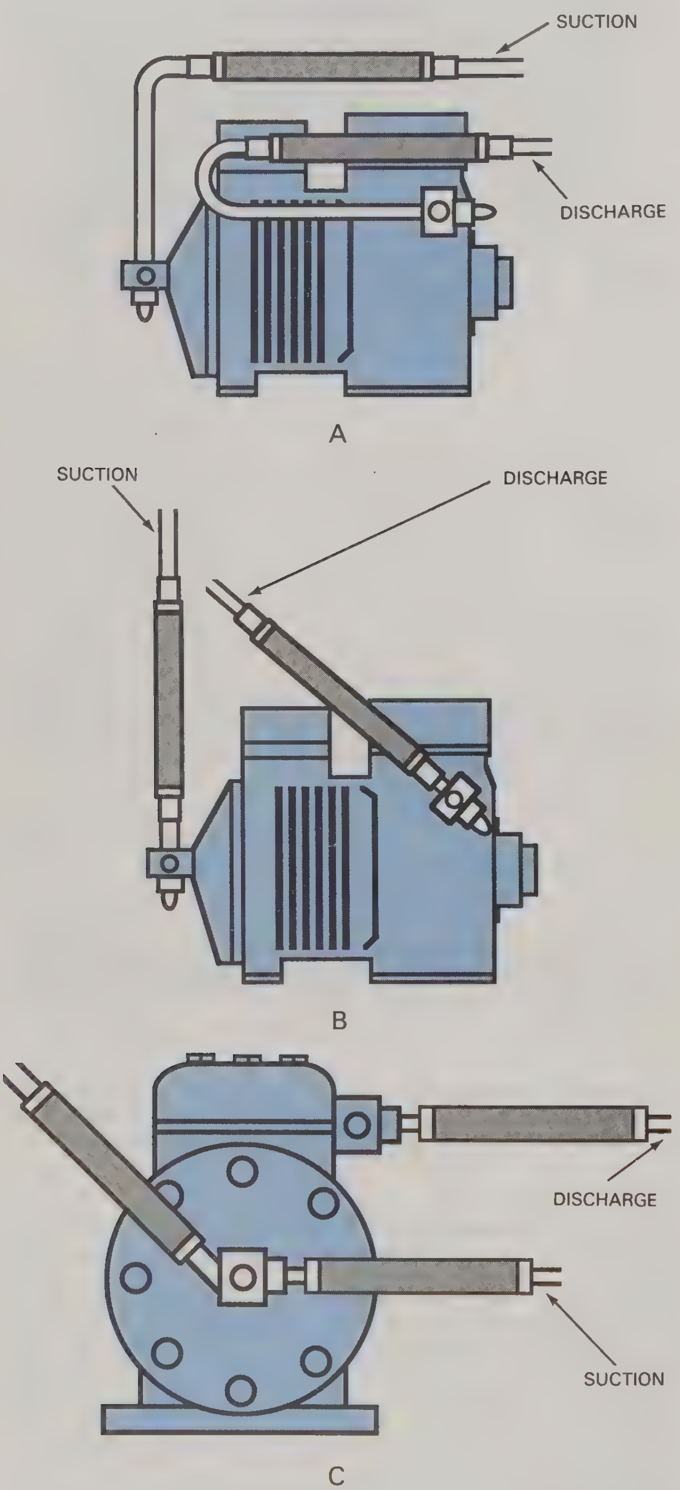


Fig. 18-28. Methods of installing vibration eliminators. A–Recommended installation, with vibration eliminators parallel with the compressor crankshaft. B–An acceptable installation. C–An incorrect installation, with vibration eliminators at right angle to the crankshaft.

COMPRESSOR DATA PLATES

The ***data plate*** mounted on each compressor contains coded information that reveals construction details of the unit. Knowing how to interpret the information (letters and numbers), can be useful to the technician. The data plate always contains the model number and serial number of the unit. These numbers *must* be used when ordering parts or obtaining an exact replacement. With these two numbers, the supplier or manufacturer has access to precise information concerning every detail of the unit. The data plate often includes useful electrical information pertaining to the motor compressor, as well.

IMPORTANT: The data plate is normally spot-welded or riveted to the unit. The manufacturer will usually *void* (not honor) the warranty if the data plate has been removed.

In this chapter, data plates from two popular compressor brands (Tecumseh and Copeland) will be explained in detail.

TECUMSEH DATA PLATES

Tecumseh does not *label* the model and serial numbers on the data plate. The technician must know where these important numbers appear on the data plate, as shown in Fig. 18-29.

Tecumseh model number codes

Model numbers are coded to reveal a great deal of important information in a very short space. Knowing how to read these numbers is not important to the service technician, but it does illustrate how important these numbers are when needing a replacement or application information. As shown in Fig. 18-30, the Tecumseh model number usually consists of two letters, four numbers, and another letter.

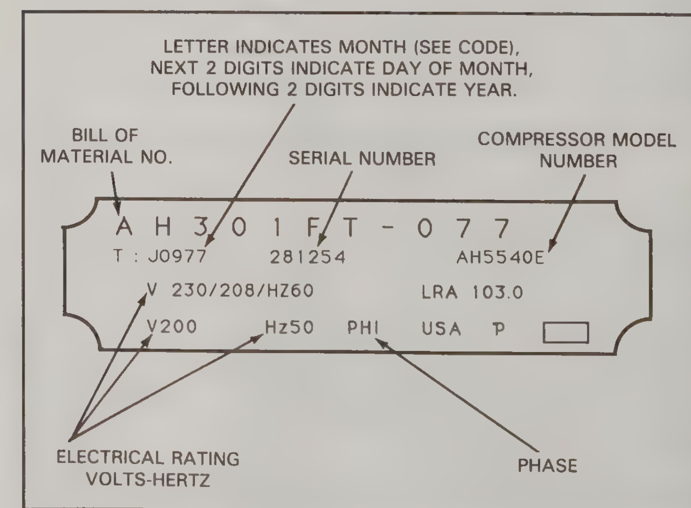


Fig. 18-29. Typical data plate used on a Tecumseh compressor. The serial number and the model number are not labeled as such on the plate. The technician must know where to look. (Tecumseh)

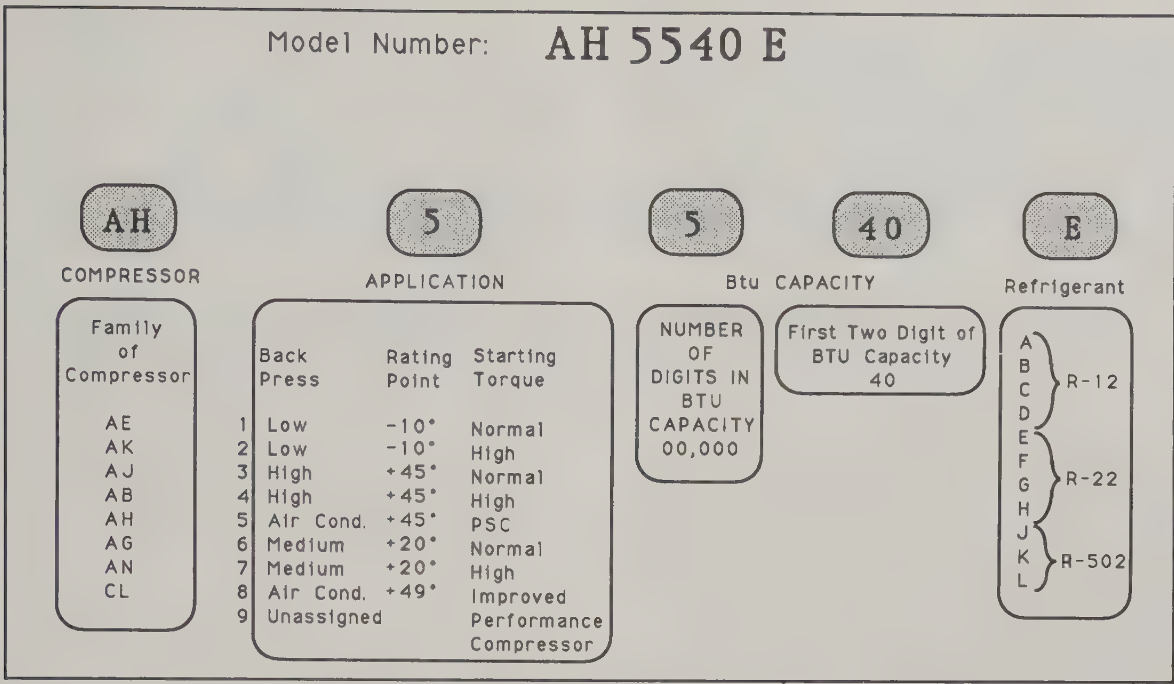


Fig. 18-30. Breakdown of information contained in Tecumseh compressor model number.

For example, AH5540E contains the following information:

- The first two letters identify the compressor family, which describes the body shape and style.
- The first number identifies the application (high-, medium-, or low-temperature) and the starting torque. 5 = Air conditioning, 45°F evaporating temperature, PSC (Permanent Split Capacitor) motor
- The second number identifies the number of digits in the Btu capacity. 5 = a 5-digit number (00,000).
- The last two numbers indicate the first two digits of the Btu capacity. 40 = 40,000
- The letter following the four numbers (E, in this case) indicates the type of refrigerant to be used:
  A,B,C,D = R-12
  E,F,G,H = R-22
  J,K,L = R-502
- Another letter may be added to the end of the model number. This letter is used to indicate specific data concerning the entire condensing unit and its accessories.

COPELAND DATA PLATES

The model number on compressors manufactured by Copeland provides a great deal of information. Unlike Tecumseh data plates, Copeland plates clearly label the model and serial numbers. See Fig. 18-31.

A typical model number might be 4RAl-1000-TFC-200 This number identifies a Copeland motor-compressor as follows:

- The first group of numbers and letters (4RA1) identifies the characteristics of the compressor:
  4 = compressor family (body shape and style)
  R = refrigerant-cooled ("D" indicates Discus)
  A = 2380 cubic feet per minute displacement
  1 = basic physical characteristics
- The second group of numbers (1000) identifies the horsepower (1000 = 10 horsepower).
- The third group consists of letters (TFC) that identifies electrical characteristics of the motor:
  T = three phase
  F = internal motor protection
  C = 208/230 volts, 3 phase, 60 hertz
- The fourth group of numbers is used for complete condensing units (200 identifies specific bill of materials and product variations).

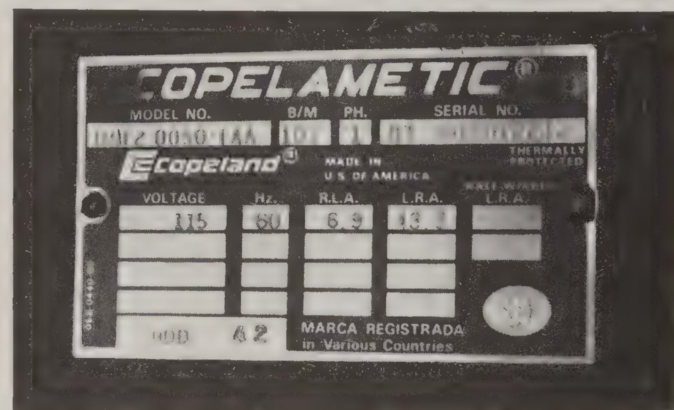


Fig. 18-31. Typical data plate for a Copeland-manufactured compressor. Model and serial numbers are easy to identify.

Copeland serial numbers

The serial number on a Copeland compressor provides both an identification number and a record of the

date of manufacture. It is composed of eight digits. The first two identify the year of manufacture; the third is a letter indicating the month. Months of the year are represented by the first twelve letters of the alphabet (A for January, B for February, etc.). The last five digits of the serial number are assigned in sequence for each month's production. For example, the serial number shown in Fig. 18-31 (87A-07742) would indicate:

87A = manufactured in January, 1987
07742 = the 7742nd unit built in January, 1987.

SUMMARY

Proper lubrication and cooling of the compressor is necessary for proper operation and long life. Refrigeration oils have special qualities that allow them to withstand extreme temperature changes while maintaining good lubrication. Some oil circulates with the refrigerant, so provision must be made to assure proper oil return to the crankcase. Good piping practice, oil separators, and oil pressure safety controls are used to assure proper compressor lubrication.

Several methods are used to eliminate possible liquid migration to the compressor. Liquid migration causes severe slugging problems, so crankcase heaters, suction accumulators, and pumpdown cycles are used to prevent it.

Vibration eliminators are used to absorb vibration caused by starting and stopping the compressor. Vibration causes copper tubing to become work-hardened and crack open, thus suffering loss of refrigerant.

Compressor data plates contain important coded information, such as model and serial numbers needed to obtain correct parts and replacements. Data plates must not be removed from the unit.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Refrigeration oil is a specially prepared ________ oil.
2. Oil kept in open containers will absorb ________
3. Name two methods of compressor lubrication.
4. The oil pressure safety control operates on the difference between ________ pressure and the ________ pressure.
5. The oil separator is designed to separate oil from ________ and return the oil to the ________.
6. True or false? As the suction pressure goes down, compressor capacity goes down, as well.
7. Why should the clearance pocket be kept small as possible?
8. Compression ratio is figured by dividing the absolute ________ pressure into the absolute ________ pressure.
9. As head pressure increases, does the compression ratio increase or decrease?
10. Because of high compression ratios, two-stage compressors are used in ________ temperature applications.
11. ________ are used to control compressor capacity.
12. Name three methods of compressor cooling.
13. The crankcase heater prevents ________ from migrating to the crankcase during the off cycle.
14. True or false? Liquid slugging can cause severe damage to the suction valve reed.
15. Where are the model and serial numbers found on a compressor?

Chapter 19

WHAT IS ELECTRICITY?

After studying this chapter, you will be able to:
- *Use electrical terminology correctly.*
- *Demonstrate proper use of electrical test meters.*
- *Describe the use of Ohm's Law.*
- *Identify open circuits and short circuits.*
- *Determine proper wire size for various uses.*
- *Select and use proper insulation on conductors.*
- *Correctly connect loads and switches in electrical circuits.*
- *Describe the differences and functions of various types of plugs, receptacles, and switches.*
- *Demonstrate how to safely connect portable electric power tools.*

NEW WORDS

alternate
alternating current
ammeter
ampacity
amperage
ampere
atoms
busbar
circuit
circuit breakers
conductance
conductor
conduit
contacts
continuity
conversion devices
coulomb
counter-electromotive force
current
dead short
deenergized
direct current
disconnects
double-pole, double-throw switch
double-pole, single-throw switch
electric power
electricity
electromotive force
electrons
frequency
fuses
ground fault
grounded
insulators
intensity
line voltage
load
lockout
multimeters
National Electrical Code (NEC)
neutral
neutrons
nucleus
ohm
ohmmeter
Ohm's Law
open circuit
parallel
phases
pole
polyphase generation
potential difference
protons
reactive
resistance
resistive
safety ground
schematic
series
short circuit
single-phase
single-pole, double-throw switch
single-pole, single-throw switch
stranded wire
switch
tagout
three-phase loads
throw
valence electrons
value
voltage
volts
VOM
wattmeter
watts
wire
zero potential

UNDERSTANDING ELECTRICITY

Understanding electricity and how it performs useful work is not difficult. In this chapter, basic principles and terms are used to explain how electricity is produced, used and controlled, and how electrical energy is used to automatically control and operate equipment. Also covered are electrical safety, troubleshooting, and making repairs.

Understanding electricity and circuitry is important for troubleshooting system problems and performing routine repairs. About 70 percent of heating and cooling system service calls are for electrical problems.

ENERGY CONVERSION

Electricity is a form of energy. Energy cannot be destroyed, but can be converted from one form of energy to another. For example, heat energy is used to produce electricity and the electricity is used to produce light energy. The reverse is also possible. Electrical appliances and other devices are designed to convert electrical energy to another form of energy, thus performing useful work.

ELECTRICAL SAFETY

Approximately 1000 people are killed by electricity every year. About one-half of these electrocutions occur on low voltage: ordinary house current can kill you in a fraction of a second. These deaths usually occur because electrical equipment doesn't take chances... *people* do.

Never let your body become a pathway for electron flow. When electricity is contained within the conductors and devices where it is supposed to function, there is nothing to fear. When damage occurs within the device, however, you are likely to get shocked. An electrical shock may not be fatal, but can cause you to jump or fall off a ladder or scaffold and injure yourself. Never become overconfident or take unnecessary risks. Your life may depend on it!

WARNING: Never work on an electrical circuit unless it has been ***deenergized*** (turned off). Use a voltage tester to check the circuit *before and after* it is turned off. Always recheck the voltage tester on a live circuit to be certain the meter is working properly. (Meters and probes can become damaged and give false readings.) Be certain the circuit cannot be energized while repairs are being made. Lock the main switch in the "open" position (called ***lockout***). Also, tag all operator switches to inform others that repairs are in process (called ***tagout***). See Fig. 19-1.

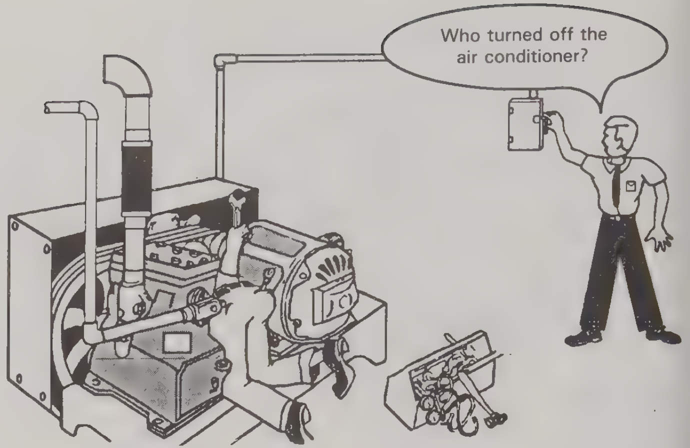


Fig. 19-1. Lockout and tagout all switches to be sure the circuit is not energized while you are working on it. Failure to do so could have serious, even fatal, results.

WHAT IS ELECTRICITY?

Electricity is a form of energy that involves the movement of electrons from one atom to another. All matter is composed of ***atoms,*** the smallest particle of any element. Atoms are fantastically tiny, but are potentially a vast source of energy. The center of an atom is called the nucleus. This ***nucleus*** contains a number of protons and neutrons. ***Protons*** have a positive charge (+) and ***neutrons*** have no charge (are neutral). The atomic number of an element indicates the number of protons in its nucleus.

Orbiting around the nucleus are ***electrons,*** which have a negative charge (-). The number of electrons orbiting is normally equal to the number of protons in the nucleus. The positive charges in the nucleus exert a strong attractive force that holds the negatively charged electrons in orbit around the nucleus. See Fig. 19-2.

ELECTRON MOVEMENT

Electrons that are in orbit closest to the nucleus are tightly bound to the nucleus and can break free only with great difficulty. Electrons orbiting farthest from the nucleus are more lightly held and can move from one atom to another. They are called free electrons or ***valence electrons.*** When an atom loses an electron, it becomes positively charged, because it has an excess proton. An atom that gains an electron will become negatively charged, because it has one more electron than it has protons. See Fig. 19-3.

The energy released by the movement of free electrons from one atom to another is called ***electricity.*** Atoms try to balance between protons and electrons (maintain equal numbers of positive and negative

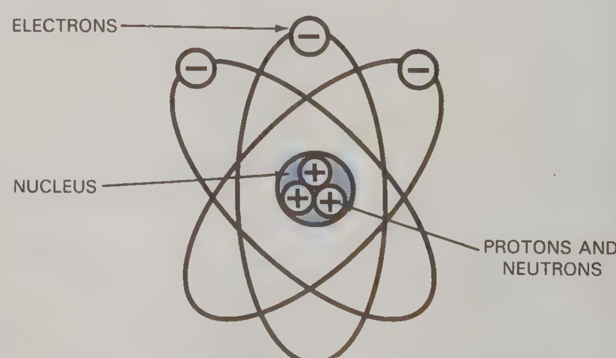


Fig. 19-2. Negatively charged electrons orbit around the nucleus of an atom. The nucleus contains positively charged protons and neutrons, which have no electrical charge.

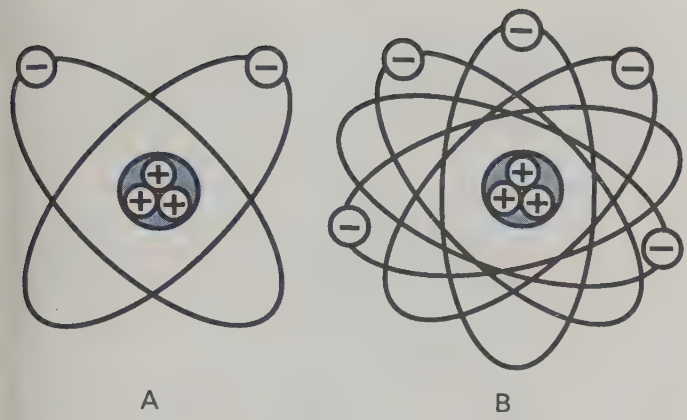


Fig. 19-3. Positively and negatively charged atoms. A–If an atom has three protons in its nucleus, but only two electrons, it will have three positive charges and two negative charges. This makes it positively charged overall. B–With three positively charged protons and five negatively charged electrons, this atom will have an overall negative charge.

charges). Various methods have been discovered to force electrons to move from one atom to another. This movement produces electrical energy that can be converted to another type of energy. Electrical energy ***conversion devices*** (toasters, light bulbs, motors, etc.) are used to perform some type of useful work.

The Law of Electrical Charges states: *like charges repel and opposite charges attract.* When a substance having excess electrons contacts a substance that is deficient in electrons (a potential difference), electrons will move from atom to atom. To make electricity perform useful work, a constant and steady movement of electrons must be produced.

VOLTAGE

A ***potential difference*** exists when the electrical charge (positive vs. negative) between two points is not in balance. This potential difference causes electrons to flow from negative to positive. The unit of measurement for potential difference is the *volt*. Potential difference (or ***voltage***) is another way of describing the ***electromotive force*** (emf) that causes electrons to move.

Electromotive force

To cause electron movement, a potential difference must be created between two points. Therefore, a local power plant generates the necessary electromotive force (emf) to create a potential difference. This force (voltage) is comparable to water pressure. The power plant produces pressure high enough to maintain proper voltage through wires over long distances. This high voltage is reduced to lower levels before use by consumers.

Alessandro Volta, an Italian physicist, discovered the principle of this pressure in 1798, and chose to call it electromotive force (emf). Mathematicians use the letter "E" to describe electromotive force. Most people refer to emf, however, as *voltage*. The terms electromotive force, voltage, potential, and pressure actually describe the same thing. Electromotive force is *not* electricity, however. It is the driving force that creates a *potential difference,* which in turn, causes electrons to move from one atom to another.

To obtain electron movement, a potential difference must exist from one point to another. This is much like water pressure. Water will not flow unless a pressure exists to push the water through the pipes. The pipes serve as a ***circuit*** (pathway) for water traveling to an area of lower pressure.

The amount of emf is measured in ***volts*** with an instrument called a voltmeter. Voltmeters measure potential difference between two specific points. Some voltmeters provide precise readings, while others indicate only approximate readings. All voltage testers have two probes. The meter indicates potential difference between the points touched by the two probes. Voltmeters are frequently used to check electrical circuits. Proper placement of the probes, and an understanding of the readings, are critical to proper troubleshooting procedures.

As noted, voltage is the force that causes electrons to move. Electrons cannot move, though, unless they have a place to go. Electrical energy convertors (appliances and other devices that convert electrical energy to another form of energy) are designed for connection between points of potential difference. The connecting wires must provide a complete circuit (pathway) for electron flow. Electrons cannot flow through an open switch or a broken wire. See Fig. 19-4.

When voltage is supplied to the energy conversion device and a potential difference exists, the device should operate. If it does not, then the device is defective. A voltage tester can quickly identify this problem, as shown in Fig. 19-5.

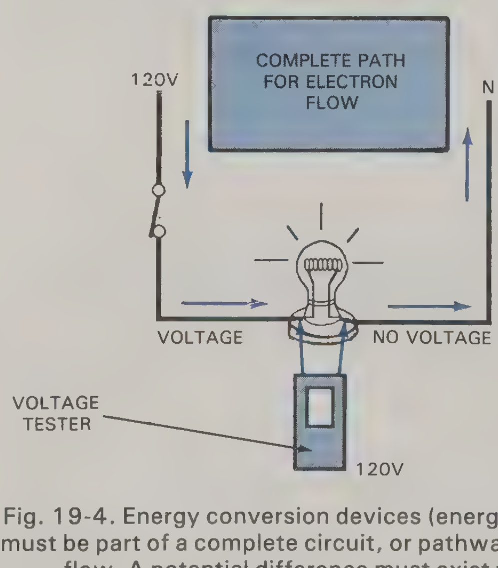


Fig. 19-4. Energy conversion devices (energy convertors) must be part of a complete circuit, or pathway for electron flow. A potential difference must exist for flow to begin and continue.

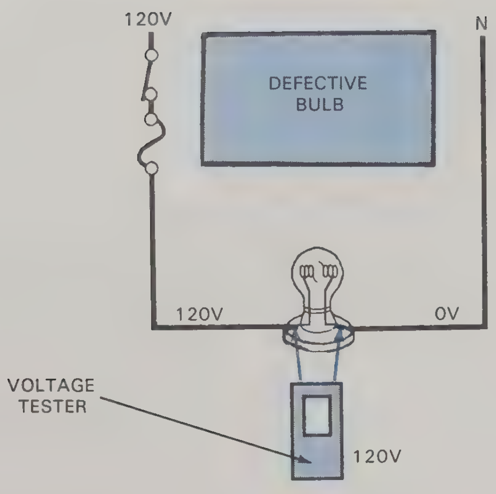


Fig. 19-5. A defective bulb causes a break in the complete path, or circuit, between points of potential difference. The potential is the same on either side of the break, so electrons cannot flow.

The voltage tester reads zero when no potential difference exists; when voltage and polarity are the same at both probe locations. There must be a difference for the voltmeter to register a voltage reading. This fundamental principle can be used to check fuses and switches with a voltage tester. See Fig. 19-6.

WARNING: Never touch an electrical wire just because a zero voltage reading was obtained: you may be reading the same potential (no difference) between the probes.

Additional voltage tests must be made to determine if voltage is present. Your body is zero voltage and could provide the necessary potential difference for electrons to flow to ground. See Fig. 19-7 .

How electrons move

The power plant does not *produce* electrons; they are already inside the copper conductors (wires). The copper conductors provide the necessary free electrons, as well as the proper pathway for electron movement.

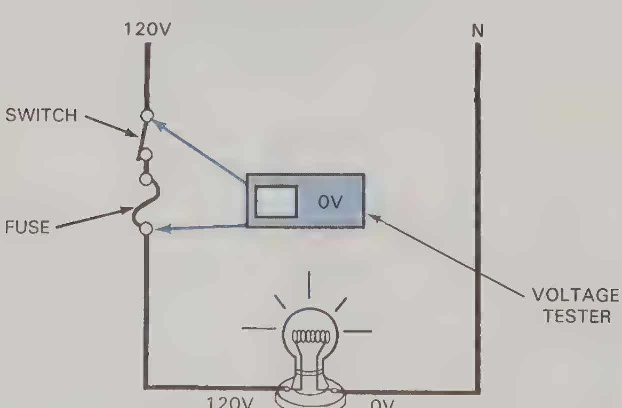


Fig. 19-6. The voltmeter will read zero when the potential is the same at both probes. No potential difference exists across the switch and fuse.

The electromotive force produced by the power plant's generator makes free electrons travel to the next atom within the conductor (wire). This electron movement from one atom to another occurs throughout the length of the conductor. The movement of electrons is very rapid and much like a "domino effect." An electrical impulse travels through a conductor at a speed of about 186,000 miles per second. To better understand this effect, picture a long tube, filled with ping-pong balls and reaching from New York City to Chicago. See Fig. 19-8.

Because the tube is completely filled, if someone in New York City inserts one ball, a ball will immediately pop out in Chicago. If more balls are inserted at New York City and the corresponding number fall out the other end, this would be an example of direct current (electron flow is in one direction). If additional balls were alternately inserted at each end, it would be an

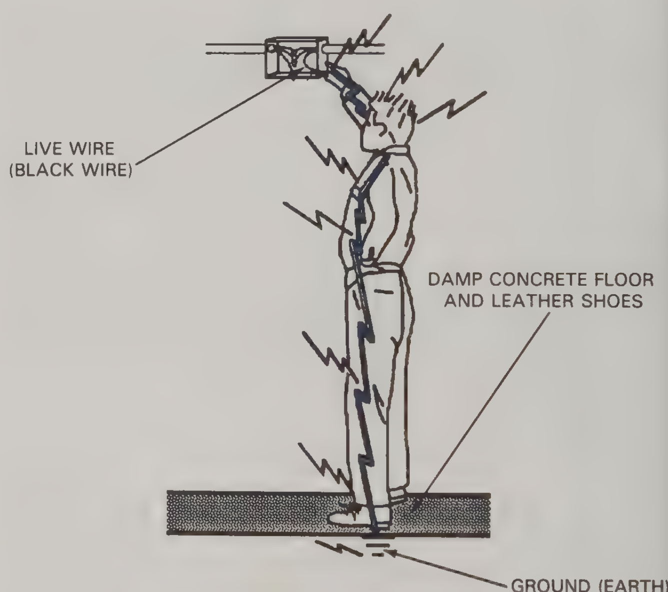


Fig. 19-7. Always exercise care to prevent becoming part of an electrical circuit. Your body could provide a path for electron flow, with painful (or even fatal) results.

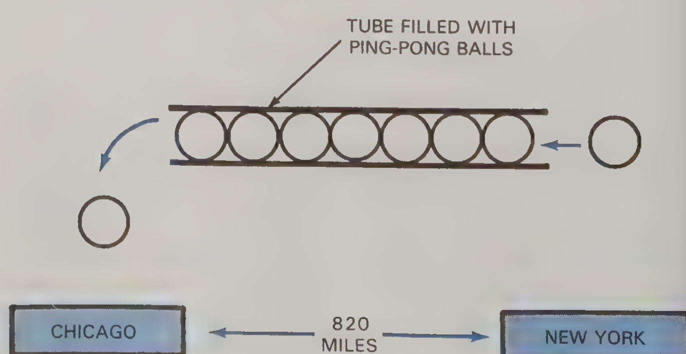


Fig. 19-8. An example of how an electrical impulse travels. If a ball is inserted at one end, another ball emerges from the other end.

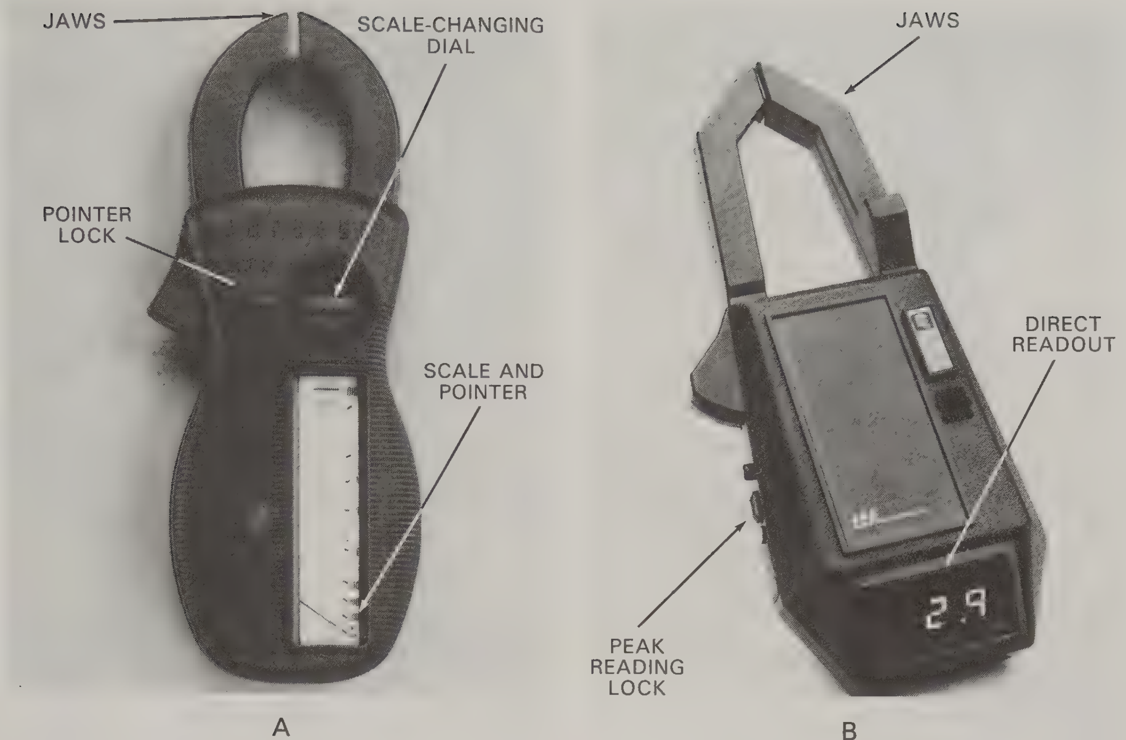


Fig. 19-9. Clamp-on ammeters. A–Analog-type meter with pointer and scale. (Amprobe) B–Digital-type meter with direct readout. (TIF)

example of alternating current. Current flow would *alternate,* moving first in one direction, then the other. It is electron *movement,* regardless of direction, that produces electrical energy.

AMPERAGE

In 1836, a French physicist, Andre M. Ampere, measured the number of electrons flowing past a given point in one second. This unit of measurement was called a coulomb of electricity. A ***coulomb*** equals 6.25 x 10^{18}, or 6,250,000,000,000,000,000 electrons. The word coulomb is used only in scientific work and in textbooks to describe this electron flow.

The words ***ampere,*** amperage, amps and current are frequently used when describing the flow of electrons in a conductor. An ***ammeter*** is used to measure electron flow, or ***current.*** The clamp-on ammeter is most common. It is available as an analog type, with needle pointer and scale, or with a digital readout. See Fig. 19-9.

When electrons flow through a conductor, a magnetic field is created around that conductor. The strength of the magnetic field is determined by the quantity of electrons flowing in the conductor: high current flow produces a strong magnetic field, low current flow produces a weak magnetic field. When electrons are not flowing, no magnetic field exists. Fig. 19-10 illustrates these conditions.

When the jaws of an ammeter are clamped around a single conductor, the meter measures the *intensity*

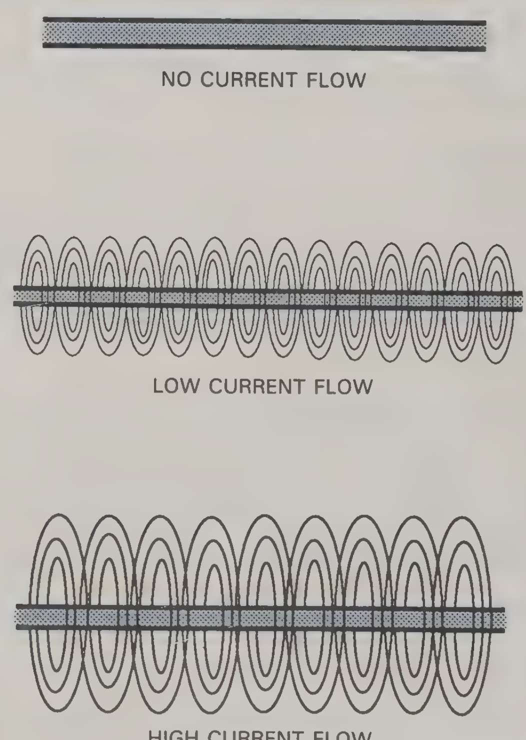


Fig. 19-10. Strength of the magnetic field around a conductor is determined by current flow. When no current is flowing (top), no magnetic field is generated. With a low current flow (center), a weak field is generated. When current flow is high (bottom), a strong magnetic field results.

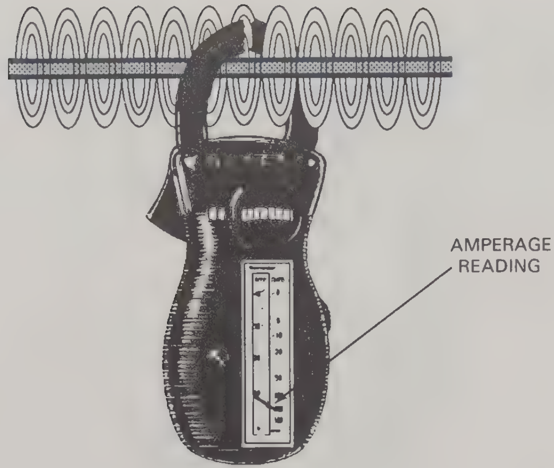


Fig. 19-11. When the ammeter's jaws are clamped around a conductor, the meter reads the intensity of the magnetic field. It then converts this information to an amperage reading.

(strength) of the magnetic field. The ammeter then converts this information to an amperage reading, Fig. 19-11. Because the ammeter measures *intensity,* the letter "I" is used in mathematical problems to indicate Intensity of electron flow.

The ammeter is designed to read the magnetic field around *one* conductor. Do not clamp the jaws of the meter around two different conductors at the same time. The two wires will be of opposite polarity (one positive and one negative) because the currents are flowing in opposite directions. The two magnetic fields will cancel one another and give a false meter reading of zero.

RESISTANCE

In electricity, ***resistance*** refers to anything impeding (working against) the movement of electrons. Various types of resistance are used to convert electrical energy to another form of energy. It is the resistance that converts energy to do useful work.

Electron flow is energy in motion and must be *controlled.* The resistance controls the amount of electron flow, and this controls the rate at which useful work is performed. Energy conversion devices are designed for converting a specific amount of electricity into another form of energy. The conversion device cannot function properly if the electron flow (***amperage***) is too high or too low.

Types of resistance

There are two important types of resistance, resistive and reactive. A resistance that is ***resistive*** remains constant (does not change). Examples of such a fixed resistance are: incandescent light bulbs, toasters, or electric heaters. Each has a fixed (constant) resistance to control electron flow during operation.

With a fixed resistance, higher voltage will increase current flow and lower voltage will decrease flow. If resistance is increased, current flow decreases; if resistance is decreased, current flow increases.

The ***reactive*** form of resistance is found in situations that involve devices with a magnetic coil that acts somewhat like a generator. The coil produces a magnetic field and voltage of its own that is in direct opposition to the supply voltage. This *counter-voltage* becomes a resistance that decreases current flow. Counter-voltage is generally described as ***counter-electromotive force (c-emf).*** Motors, transformers (primary side), and solenoid coils are examples of devices that produce magnetic fields. The amount of counter-emf that is generated is determined by the strength of the magnetic fields. The c-emf acts as additional resistance, created whenever the device is operating. Counter-emf is further explained in the chapter on motors.

OHM'S LAW

The exact relationships among voltage (E), amperage (I) and resistance (R) were discovered at the beginning of the nineteenth century by a German scientist, Georg Simon Ohm. These relationships, summarized as ***Ohm's Law,*** can be used to predict and control electricity. The unit of resistance, the ***ohm,*** was named in honor of the scientist.

Ohm's Law proves that $E = I \times R$ (voltage equals amperage times resistance). This mathematical formula is best remembered in the form of a "pie," Fig. 19-12. The horizontal line across the middle indicates *division,* and the vertical line down from the middle indicates *multiplication.*

To use the pie, cover the item to be determined. Then perform the math operation indicated by the horizontal or vertical line. See Fig. 19-13. For example, to discover E, you must multiply $I \times R$; to discover I, divide R into E. The capital letter "R" is used to indicate resistance. Another symbol for resistance is the Greek capital letter omega (Ω).

Ohm's Law is used to design electrical devices and troubleshooting such devices. Suppose an electric frying pan has a heating element designed to convert 5 amps into heat energy. With normal household voltage (120V), how much resistance is required? Divide E (voltage) by I (amperage): $120 \div 5 = ?$. The heating element would have a resistance of 24 ohms ($E \div I = 24$). A thermostat

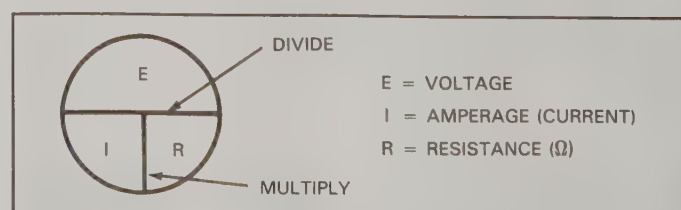


Fig. 19-12. The Ohm's Law "pie" makes it easy to determine one value of an electrical circuit when the other two are known. The horizontal line indicates division, while the vertical line indicates multiplication.

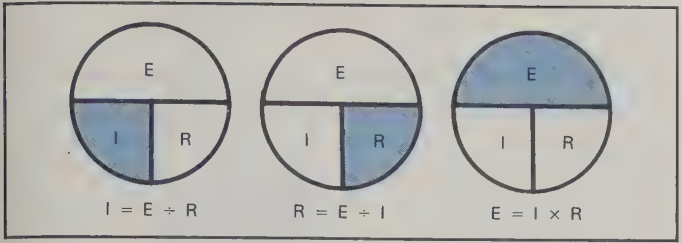


Fig. 19-13. To use the ''pie'', cover the value to be determined, then multiply or divide remaining values as indicated by the lines. To find amperage, divide voltage by resistance. To find resistance, divide voltage by amperage. To find voltage, multiply amperage times resistance.

is installed to control the temperature of the frying pan. The thermostat will turn the heating element on and off at temperatures selected by the user.

OHMMETER

An *ohmmeter* is used to check resistance. These meters are very sensitive instruments that actually measure resistance to the low voltage (1.5V or 9V) supplied by an internal battery. A zero adjustment knob provides recalibration to compensate for a weakening battery. See Fig. 19-14.

When using an ohmmeter, power to the circuit must be turned off and disconnected. Failure to disconnect the power supply will cause severe damage to the ohmmeter. All wire connections should be removed to isolate the device being checked. This prevents an incorrect reading by blocking any electron flow through another circuit.

Fig. 19-14. An ohmmeter contains its own power supply (a small battery) and actually reads resistance to the battery voltage. Most technicians today use a multimeter, like the one shown, that can be used to read resistance, voltage, or amperage. On this meter, resistance values, in ohms, are read from the uppermost scale. (Simpson Electric Co.)

The ohmmeter is often used to check the accuracy of a resistance, since it indicates a specific ohm ***value*** (number of ohms). If the correct resistance (number of ohms) is known or calculated, the ohmmeter is used to check this resistance. See Fig. 19-15.

Continuity

An ohmmeter is used to check ***continuity*** (existence of a complete path for electron movement from one point to another). A meter reading of zero resistance proves that there are no broken wires, blown fuses, or open switches in the electrical circuit. See Fig. 19-16.

When checking continuity, the ohmmeter is adjusted to the lowest resistance scale (R × 1). Do not use the

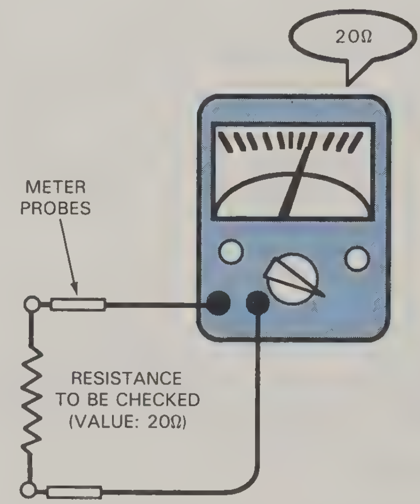


Fig. 19-15. The ohmmeter can be used to check the accuracy of a resistance. Resistance is displayed in ohms on the meter scale.

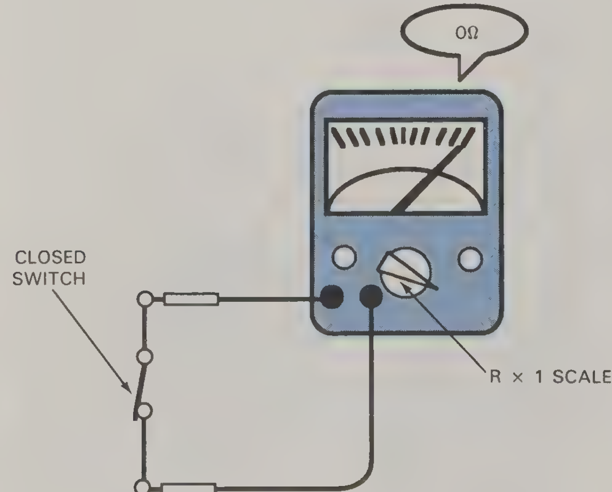


Fig. 19-16. A reading of zero resistance (0Ω) shows that there is continuity in the component or circuit. A complete path exists for electron movement. When checking continuity, the lowest resistance scale setting (R × 1) is used.

meter multipliers (R × 10, R × 100). All electrical circuits contain a minimal resistance to electron flow, due to length of conductors, connections, and switches. Such resistance is normal and does not affect continuity readings. This built-in circuit resistance cannot be read on the scale unless the meter is calibrated to multiply the reading. Some ohmmeters automatically multiply until a reading is obtained.

Open circuit

The ohmmeter indicates an ***open circuit*** by showing extremely high resistance. Electrons cannot flow because of an open switch, blown fuse, broken wire, or similar cause. The resistance is so high the meter cannot measure it, so it is indicated by the symbol for infinity (∞). See Fig. 19-17.

Short circuit

A ***short circuit*** provides a "short cut" for unlimited electron movement (current flow). Resistance is required to control current flow. The ohmmeter detects a short circuit by indicating zero resistance between two points that *should* have resistance. A short circuit means there is continuity (a complete circuit) where none should exist. There is little or no resistance in a short circuit. See Fig. 19-18.

Too much current flow causes major problems. Wires become hot, fuses blow, fires occur, and devices may explode. A short circuit presents a dangerous condition due to unrestricted current flow. ***Fuses*** and ***circuit breakers*** are used to protect the circuit, not people.

MULTIMETERS

Electrical test meters are often combined into one instrument that performs multiple functions. These are called ***multimeters*** or ***VOM (volt-ohm-milliammeters)***,

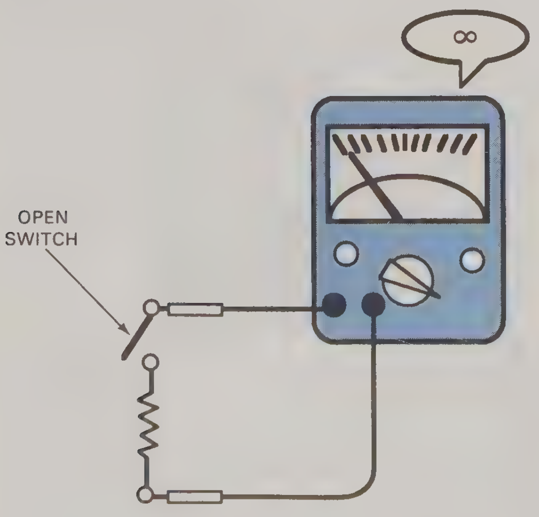


Fig. 19-17. An open circuit (break in the path) shows resistance at infinity. Electrons are unable to flow because of the break.

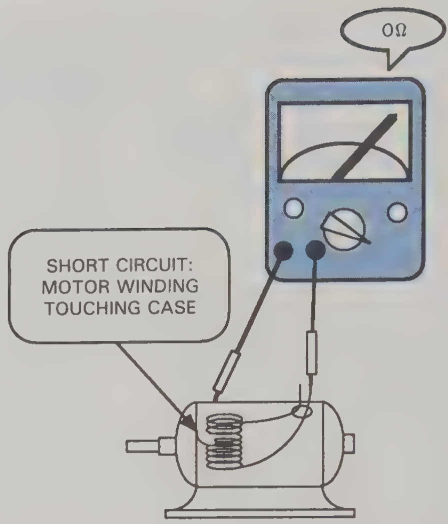


Fig. 19-18. If a short circuit exists, an ohmmeter will show no resistance between points where there should be resistance. A short circuit is a dangerous condition.

Fig. 19-19. A milliampere is 1/1000th of an ampere, so the milliampere range on the meter allows the detection of very small currents. To achieve proper results with a multimeter, probes must be correctly hooked up, and the dial settings must be chosen correctly. Always consult the manufacturer's instruction manual when unsure of the proper hookup. Mistakes will cause false readings and meter damage.

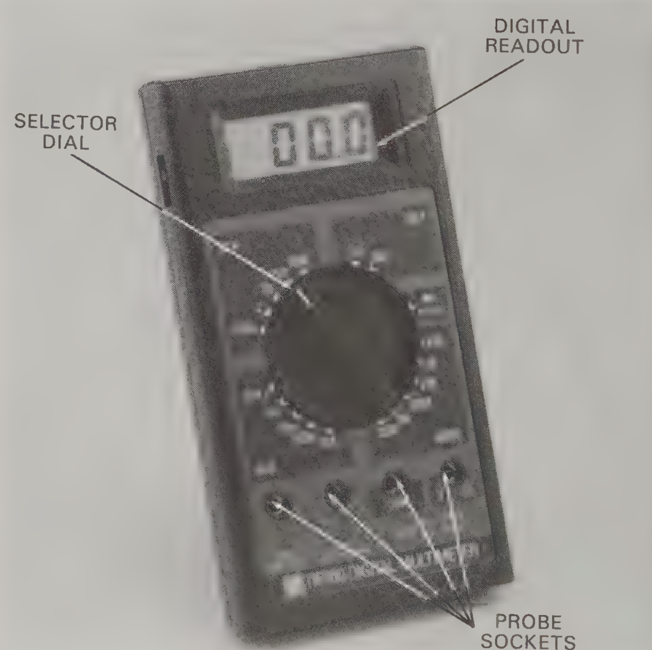


Fig. 19-19. A multimeter measures AC and DC voltages, ohms, and current in amperes, milliamperes or microamperes. Technicians often refer to this type meter as a VOM (volt-ohm-milliammeter). Digital readouts have become more popular than the traditional pointer and scale models, since they are easier to read accurately. (TIF)

ELECTRICAL POWER

An English scientist, James Watt (1763-1819), discovered the method for measuring ***electric power*** (the rate at which electrons are used to perform useful work). Work is measured in units called ***watts***, which are calculated by multiplying amperes times volts. The calculation can be expressed as either W = I × E or as P = I × E. You can use either "P" for power or "W" for watts, because they represent the same thing.

A diagram that works exactly like the Ohm's Law pie can be drawn to illustrate the use of this formula. The two pies are often used to determine proper test meter readings. They are also used to convert information for using different meters. For example, watts can be calculated after obtaining voltage and amperage readings. Likewise, proper amperage can be determined if watts and volts are known. See Fig. 19-20.

WATTMETER

A ***wattmeter*** is a special meter designed to measure the power (wattage) used by an appliance or home. The electric meter mounted outside a home at the point where the power line is connected is a watt/hour meter. The customer is billed according to the number of watt/hours used per month. See Fig. 19-21. A small wattmeter is sometimes used by appliance repair technicians. This wattmeter, Fig. 19-22, is connected between the power outlet and the appliance to provide a reading of the power use.

Many electrical devices indicate a wattage number on the schematic, data plate, or other label. This tells the amount of power needed to operate the device. Examples of such devices are window air conditioners, resistance heaters, and light bulbs. The wattage rating is often converted to terms more useful for troubleshooting (ohms, volts, or amperes).

CONDUCTORS

Electrical wires (conductors) provide the needed free electrons and serve as the pathway for electron flow. The wires are used to connect devices and switches to complete an electrical circuit. Metals are conductors of electricity, but not all metals conduct with equal ability.

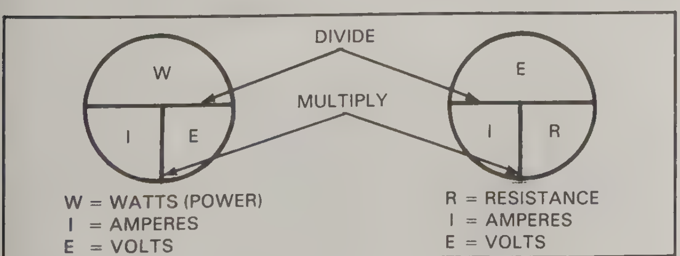


Fig. 19-20. Power can be determined by using a pie diagram like the one at left. It is used in the same way as the Ohm's Law pie at right.

Metals have an internal resistance that opposes the flow of electrons in the conductor. While *resistance* is opposition to flow, ***conductance*** is the *ease* with which the current flows. Conductance is the number of amperes flowing in a conductor per volt of applied emf.

A conductor that has high internal resistance automatically converts electrical energy to heat energy, so

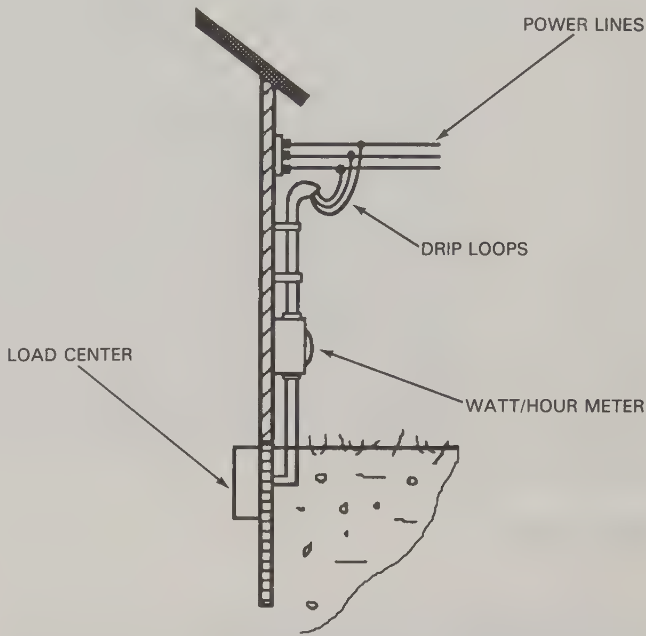


Fig. 19-21. The electric meter on a house or apartment is a watt/hour meter that records the household's power consumption.

Fig. 19-22. A digital wattmeter of the type used by appliance repair technicians. (TIF)

the conductor becomes hot. Internal resistance also causes a drop in voltage. The amount of internal resistance in a conductor depends upon the type of metal from which it is made, the wire size, length of the wire, and the ambient temperature. Materials such as tungsten alloys, nichrome, and steel have high internal resistance, so they heat up quickly. They are often used for electric heating elements.

To be a "good conductor" a material must have good conductance with low internal resistance. Fig. 19-23 is a table that illustrates the conductance and resistance of different metals.Silver, copper, and aluminum are good conductors because they have high conductance and low resistance. Copper is the most common conductor. Copper wire bends easily, has good strength, resists corrosion, and is easily joined. Aluminum is sometimes used because of its low cost. However, aluminum corrodes easily and connections have a tendency to loosen. Loose connections become hot, which can destroy insulation and causes fires. Consult your local electrical inspector before using aluminum conductors. The high cost of silver keeps it from being widely used. Its use is limited to such applications as contacts in switching devices.

WIRE SIZES

The amount of current a conductor can safety carry without becoming overheated is limited. This limited current-carrying ability is called ***ampacity.*** The ampacity of a conductor depends upon the size, length, location, and type of the wire and on the quantity of insulation.

CONDUCTANCE AND RESISTANCE OF VARIOUS METALS		
METAL	CONDUCTANCE	RESISTANCE
Silver	2207	1.0
Copper	2030	1.09
Gold	1471	1.50
Aluminum	1277	1.73
Tungsten	634	3.48
Brass	461	4.79
Iron	304	7.26
Nickel	263	8.39
Steel	235	9.39
Nichrome	34	64.91

Fig. 19-23. This table shows the conductance and resistance values of various metals. The higher the conductance value and the lower the resistance number, the better the conductor. Note the very high resistance value for nichrome, which is used as a heating element for toasters, and portable heaters.

A ***wire*** is a single strand or filament of drawn metal (if insulated, it is properly called an *insulated wire*). A ***conductor*** can be a solid wire or a group of wires twisted together (***stranded wire***). Conductors are stranded mainly to increase their flexibility.

Wire sizes in the United States are established by the American Wire Gauge (AWG) system. This system lists wire sizes as a number. The largest wire is No. 0000 (4/0), and No. 50 the smallest. Larger and smaller sizes are manufactured, but are not commonly used. Fig. 19-24 shows some common sizes for both solid and stranded wire.

The most commonly used wire sizes range from No. 18 to No. 4, but No. 12 copper wire is probably used more than any other size. It is often installed when a smaller wire would be approved. Other than cost, there is no problem with oversizing a wire. Undersizing, however, causes severe problems due to overheating. Fig. 19-25 is a table that illustrates wire sizes, resistance, and ampacity for standard sizes of copper wire.

Insulation for wires

Insulators are materials that have very few free electrons and exhibit high resistance to electron flow. Examples of insulators are glass, rubber, mica, Bakelite™, asbestos, paper, and silk. Insulation is used to prevent electrons from traveling an unwanted path. When wrapped around a conductor, insulation forces electrons to remain inside the conductor. For this reason, you should always use care to avoid damaging the insulated covering on a wire.

There is no perfect insulator. All insulators can break down due to moisture, heat, excess current flow, chemicals, or other environmental problems. Breakdown often can be avoided by increasing the thickness or the quality (or both) of insulation. Insulation can be heat-resistant, moisture-resistant, oil-resistant, or have other special qualities. The type of insulation or covering determines where the conductor can be safely used.

Manufacturers of electrical wire use letter codes to designate the type of insulation. The various types of insulation are coded by letters of the alphabet and stamped on the insulation surface. See Fig. 19-26. The most commonly used insulation types are TW, THHN, THW, or THWN. The unusual types are used for special applications. A short list of insulation types, letter codes, and locations where the conductor may be used

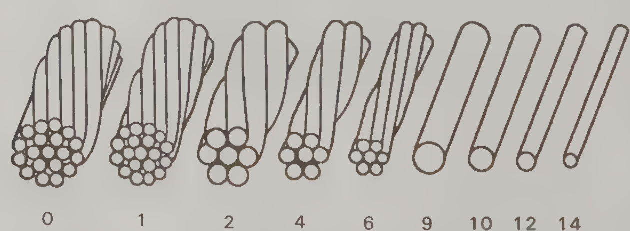


Fig. 19-24. Common sizes of solid and stranded wire. Conductors are stranded to improve their flexibility.

DIMENSIONS, TYPICAL RESISTANCES AND AMPACITY OF COMMERICAL WIRE							
		OHMS PER 1000 FT.		CURRENT CAPACITY (AMPERES)			
				COPPER		ALUMINUM	
GAUGE NO. (AWG)	DIAMETER BARE WIRE (INCHES)	70°F	167°F	TW UF	RH, RHW, THHW, THW, THWN	TW UF	RH, RHW, THHW, THW, THWN
0000 (4/0)	0.460	0.050	0.060	195	230	150	180
000 (3/0)	0.410	0.062	0.075	165	200	130	155
00 (2/0)	0.365	0.080	0.095	145	175	115	135
0 (1/0)	0.325	0.100	0.119	125	150	100	120
1	0.289	0.127	0.150	110	130	85	100
2	0.258	0.159	0.190	95	115	75	90
3	0.229	0.202	0.240	85	100	65	75
4	0.204	0.254	0.302	70	85	55	65
6	0.162	0.40	0.480	55	65	40	50
8	0.128	0.645	0.764	40	50	30	40
10	0.102	1.02	1.216	30 *	30 *	20	25
12	0.081	1.62	1.931	20 *	20 *	16	18
14	0.064	2.57	3.071	15 *	15 *		
16	0.051	4.10	4.884	10 *	10 *		
18	0.040	6.51	7.765	5 *	5 *		

* Load current rating and overcurrent protection shall NOT exceed these figures.

Fig. 19-25. Wire size, resistance, and ampacity for the most common-sized conductors are given in this table.

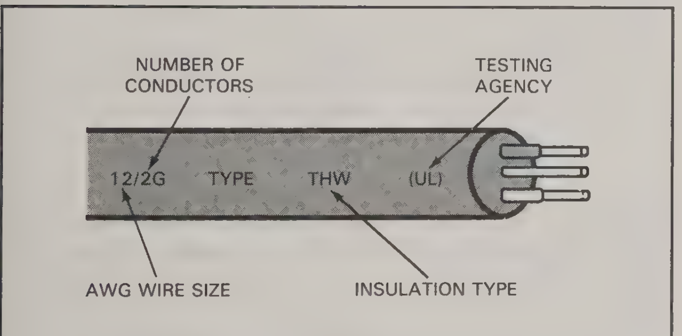


Fig. 19-26. Insulation codes and other important information is printed on the outside of electrical wire by the manufacturer.

INSULATED CONDUCTOR APPLICATIONS			
TYPE OF INSULATION	LETTER CODE	MAX. TEMP.	APPLICATION
Asbestos	A	392F	Dry locations only
Asbestos and Varnished Cambric	AVA	230F	Dry locations only
Heat Resistant Rubber	RH	167F	Dry and damp locations
Thermoplastic	T	140F	Dry locations
Moisture Resistant Thermoplastic	TW	140F	Dry and wet locations
Heat Resistant Thermoplastic	THHN	194F	Dry locations
Moisture and Heat Resistant Thermoplastic	THW or THWN	167F	Dry and wet locations
Underground Feeder	UF	140F	Moisture resistant
Varnished Cambric	V	185F	Dry locations only

Fig. 19-27. This chart shows wire insulation types, letter codes, maximum temperatures for use, and typical applications.

is shown as Fig. 19-27. Consult the NEC handbook for a complete list of insulation types.

ELECTRICAL LOADS

A ***load*** is any electrical device that converts electrical energy to another form of energy. Examples of such loads (energy conversion devices) are light bulbs, electric drills, and motors. The applied voltage and resistance determine the amount of electron flow (as described by Ohm's Law). Wattage measures the rate of energy conversion.

Manufacturers of electrical energy conversion devices (loads) install the correct resistance to perform a

particular job. It is important to know how to connect these loads to the required voltage. The voltage forces electrons through the resistance at a specific rate. If voltage is too high, the work is performed too fast. If voltage is too low, the work is performed too slowly. The amount of current flowing through the load is determined by voltage and resistance.

When connecting a load to a voltage source, a minimum of two conductors must be used. One conductor is connected to each end of the resistance. One of these wires contains excess electrons under pressure (voltage), while the other wire has zero voltage. This is a *potential difference,* so electrons flow through the resistance from one wire to the other. To function, all loads *must* be connected to a potential difference (from one side of the power source to the other). Electrons must be able to flow into and out of the load, as shown in Fig. 19-28.

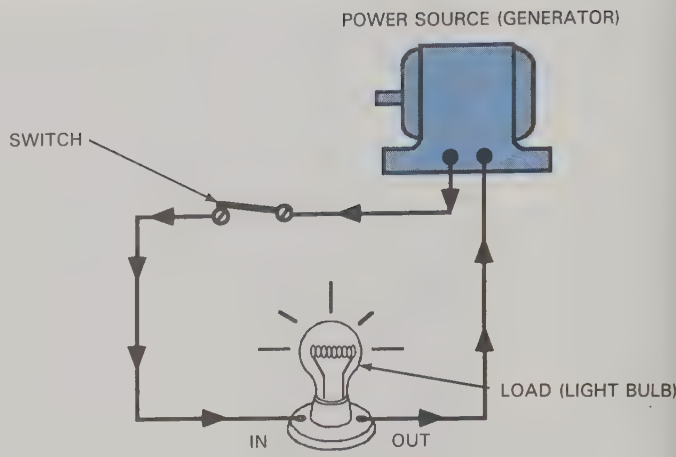


Fig. 19-28. A load, such as the light bulb, must be part of a complete circuit to function. One conductor must connect the load and the power source at each side, as shown. This provides the potential difference needed for electron flow.

SWITCHES

Unless the circuit forms a complete path for electrons to flow into and out of the load, the load cannot operate. A ***switch*** provides an easy method of stopping electron movement to the load by breaking (disconnecting) the circuit. Electrical switches are *not* a load; they offer no resistance to the flow of electrons. A switch acts like a drawbridge that opens and closes to stop and start the flow of electrons through the conductor to a load. When the bridge is "up" (switch is open), electrons cannot get past it. See Fig. 19-29.

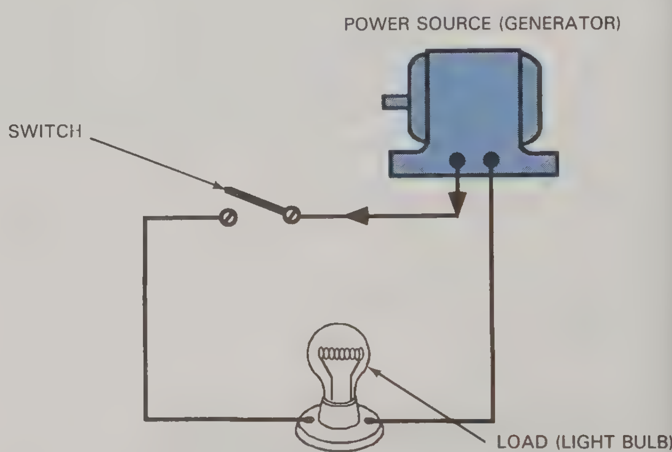


Fig. 19-29. A switch functions like a drawbridge, to control the flow of electrons. When it is closed, the circuit is complete and electrons can flow. When it is open, electron flow ceases because there is no longer a complete circuit.

Switches are connected in ***series*** with a load. This controls electrons flowing *to* the load. Switches are never connected in ***parallel*** (from one power leg to the other) with the load. Such a parallel connection permits unrestricted flow of electrons. This is called a ***dead short.*** See Fig. 19-30.

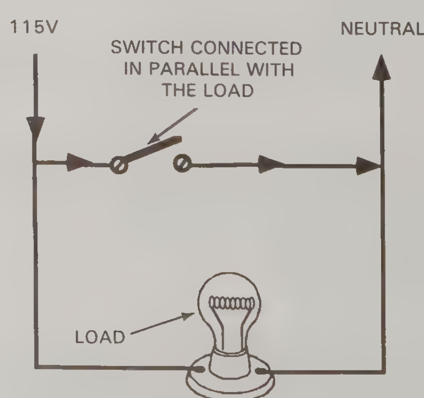


Fig. 19-30. A switch should never be connected in parallel with a load. In this circuit, the light bulb would function normally so long as the switch remained open. Closing the switch, however, would divert electron flow through the parallel conductor because it would offer less resistance. The light bulb would go out, since there would be no electron flow through it.

Series connections

More than one switch, connected in series, may be used to control a load. In a series connection, electrons are forced to travel through *each* switch before reaching the load. All the switches must be closed to complete the circuit. Switches are always connected in series with a load. See Fig. 19-31.

Parallel connections

Most *loads* are designed and manufactured to be connected in parallel, or "from one side of the line to the other." It is common practice to connect more than one load into a circuit. Each load must be connected in parallel. As shown in Fig. 19-32, this allows all the loads to be connected to a potential difference, but operate independently of one another. Opening the switch on one parallel-connected line affects only the load on that line. It would have no effect on the remaining loads.

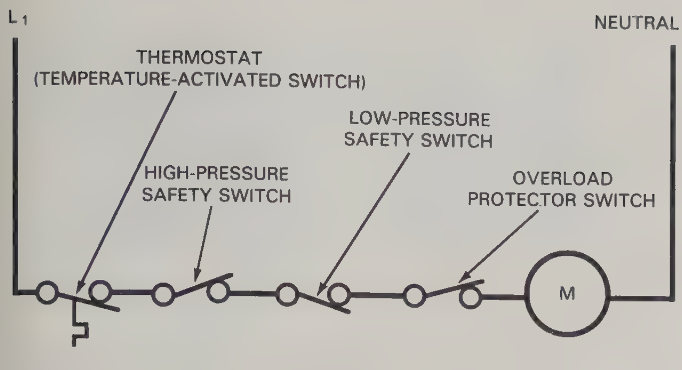


Fig. 19-31. In this series-connected motor circuit, all four switches must be closed for the motor to run. If any switch opens, the motor will stop because electron flow has ceased.

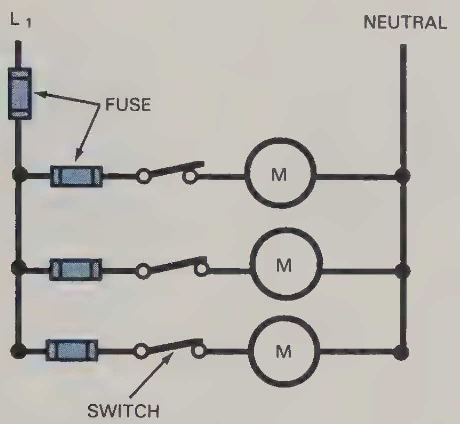


Fig. 19-32. These three loads are all connected in parallel, so each branch line is independent of the others. If the switch is opened or a fuse ''blows'' on any branch line, it would affect only the motor on that branch. The others would continue to operate.

Series-parallel connections

When more than one load is connected into a circuit, switches are required to control the individual loads. The switches are connected in *series* with the load they control, while the loads are connected in *parallel.* This is called a series-parallel connection. See Fig. 19-33.

Safety considerations

Safe wiring practice is to locate switches in the line *supplying power (voltage) to the load.* When the switch opens, voltage stops at the switch and the load is disconnected from the potential difference. If the switch is located in the *neutral* wire, electricity is available through the load. As shown in Fig. 19-34, a person touching this load could possibly complete a circuit and be injured by an electrical shock.

There are basically two types of electricity, ***direct current*** (which flows in only one direction) and ***alternating current*** (which reverses direction many times each second).

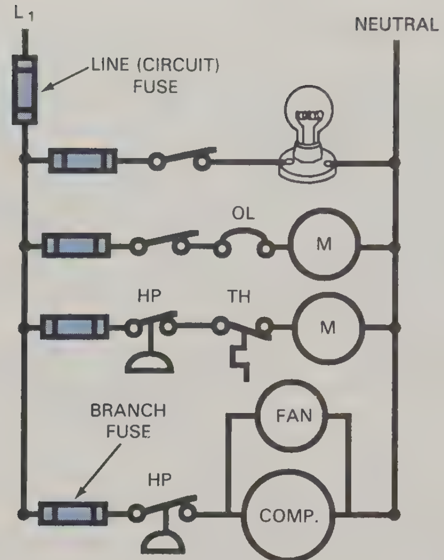


Fig. 19-33. Series-parallel connections permit each load to be controlled and operate separately. Each device (load) is controlled by one or more switches. Note that each branch line has a fuse, but that the entire circuit is also protected by a line fuse.

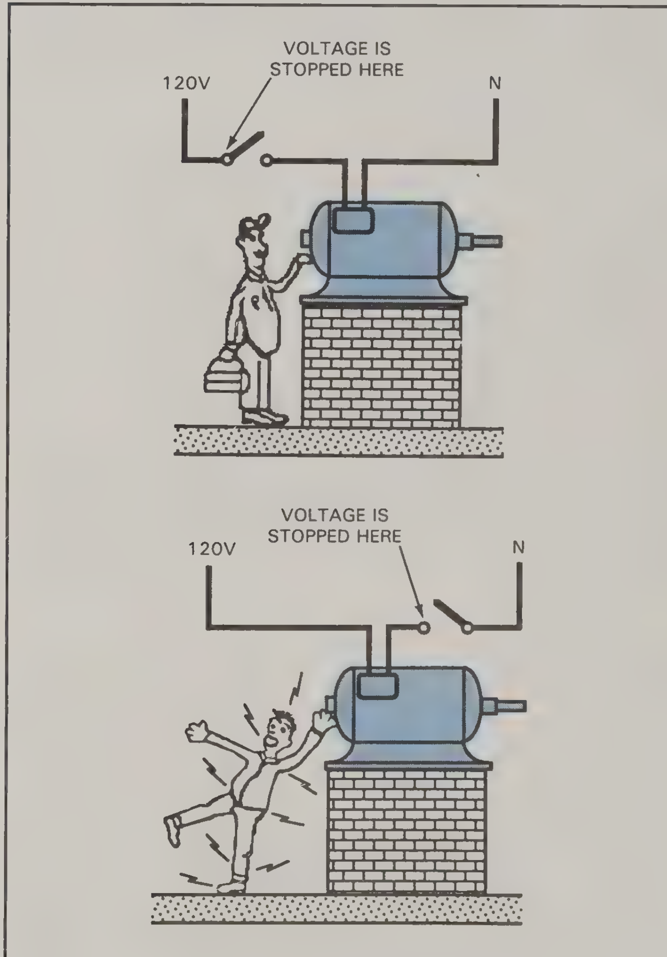


Fig. 19-34. For safety, a switch should always be located on the line side of the load, rather than the neutral side. When a switch is wired into the neutral side, a shock hazard exists, as shown.

DIRECT CURRENT (DC)

As you read earlier, electric current is the movement of free electrons in a conductor. Current flows when a potential difference is maintained. If the polarity (+ vs -) of the potential difference never changes, the current will flow in one direction. This is called direct current, or DC.

The difference in polarity determines the direction in which current flows in a circuit. Electrons normally flow from negative (-) to positive (+).

A battery, Fig. 19-35, is the most common source of DC power. It converts chemical energy to electrical energy and thus becomes a self-contained power source. To obtain current flow, a potential difference must exist between the negative and positive terminals. Direct current flows from the negative terminal (excess of electrons) to the positive terminal (deficiency of electrons). See Fig. 19-36. Direct current is usually abbreviated DC, and involves the use of DC sources, DC voltage, DC current, and DC circuits.

ALTERNATING CURRENT (AC)

Alternating current flows first in one direction, then reverses and flows in the other. Since current normally flows from negative (-) to positive (+), the polarity of the power source must alternate from - to +, and then + to -. These rapid alternations in polarity cause the electrons to rapidly move back and forth inside the conductor. It is the *movement* of electrons, not direction of flow, that produces electrical energy.

Alternating current, or AC, is the name given this reversing current. Power plants use alternators to produce a rapidly alternating polarity by rotating a conducting loop through a strong, stationary magnetic field. See Fig. 19-37.

As the sides of the rotating conducting loop cut through the stationary magnetic lines of flux, a voltage (emf) is applied to the free electrons in the conductor. As the conducting loop rotates, each side cuts the magnetic field in opposite directions. Polarity changes as each side of the loop approaches the other magnetic pole. This produces alternating polarity and an alternating current. See Fig. 19-38.

AC sine wave

The sine wave, Fig. 19-39, is used to illustrate the principle of alternating current. It shows how voltage builds up at the North pole, falls back to zero, builds up again at the South pole, and again falls back to zero.

Electromotive force (voltage) drops to zero when the conducting loop is not cutting magnetic lines of flux. This happens when the conducting loop is straight up and down. Voltage increases as more and more lines of flux are being cut. Voltage is highest when the conductor is closest to the magnetic pole and cutting lines of force at right angles. Voltage drops off as the conductor travels away from the magnetic pole.

Cycles or Hertz (Hz)

To complete one cycle, or revolution, the loop passes one magnetic pole and then the other. Complete revolutions occur at the rate of 60 cycles per second. Flow

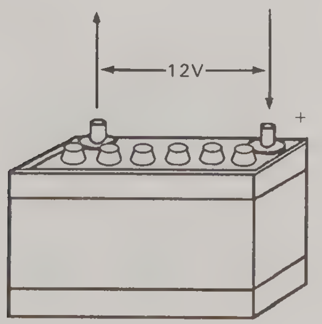


Fig. 19-35. A battery is a self-contained power source. It converts chemical energy to electrical energy.

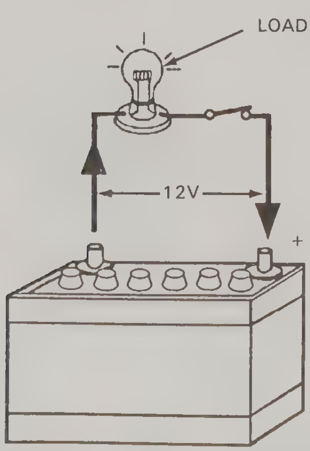


Fig. 19-36. Direct current flows in one direction, from the negative terminal of this battery to the positive terminal.

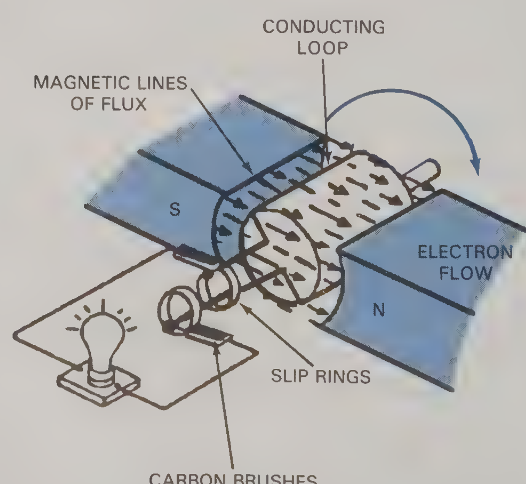


Fig. 19-37. Alternating current is produced by rapidly rotating a conducting loop (shown here in simplified form) through a stationary magnetic field. The rotation of the loop causes the generated current to reverse polarity rapidly and regularly.

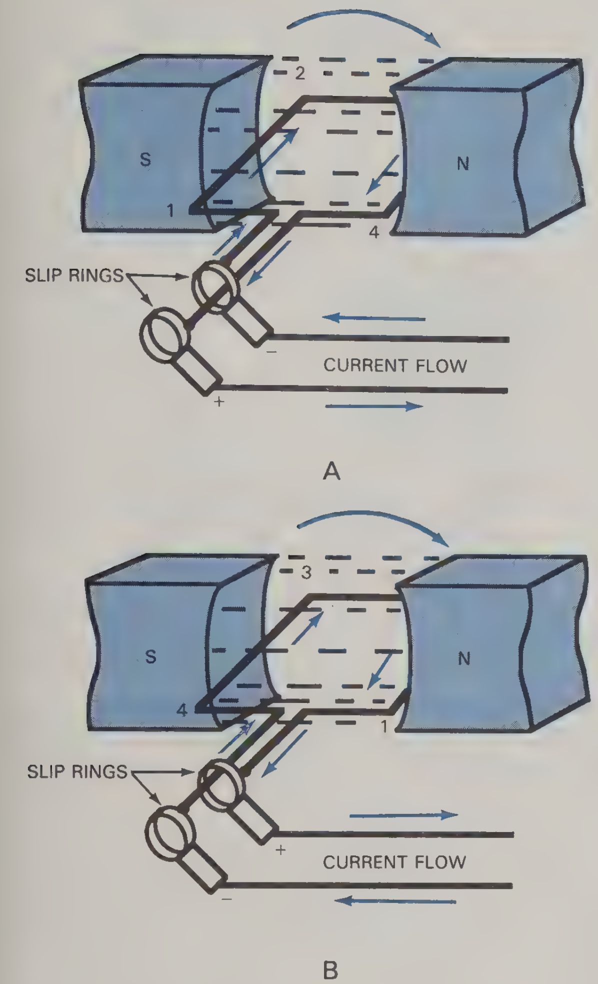


Fig. 19-38. As the conducting loop rotates, polarity changes. At top, note the direction of current flow through the side of the loop labeled 1 - 2 as it rotates upward past the South magnetic pole. Compare that to the direction of current flow, at bottom, through same side of the loop (1 - 2) as it rotates downward past the North magnetic pole.

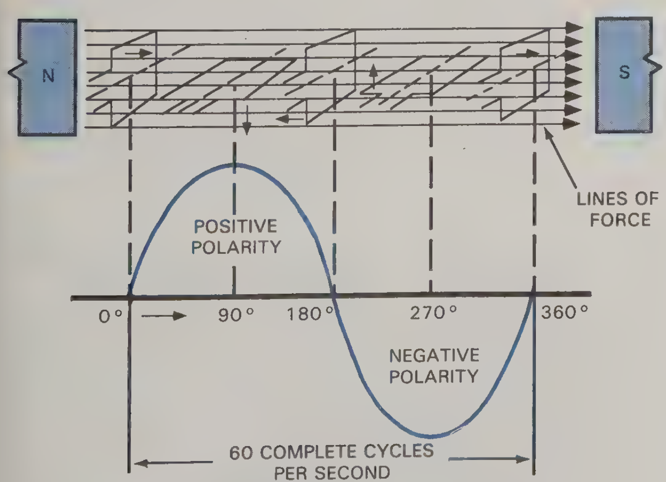


Fig. 19-39. As alternating current is generated by the rotating loop, the voltage builds to a peak, then declines to zero. It next reverses polarity and repeats the pattern in the opposite direction. The entire cycle is shown in the form of a sine wave. In North America, the frequency of alternating current is 60 cycles per second.

reversal occurs twice per cycle (1/2 cycle = N, and 1/2 cycle = S). This flow reversal (120 times per second) is so rapid that a light bulb will not flicker. The voltage and current flowing through the conductor is rather constant, due to the speed of the cycles.

The ***frequency*** of alternating current is the number of complete cycles that occur in one second. In the United States and Canada, alternating current is produced at a frequency of 60 cycles per second. Most other countries use 50 cycles per second. The unit "cycles per second" is usually referred to as hertz (Hz), to honor the German physicist Heinrich Hertz, one of the pioneers of alternating current.

POLYPHASE GENERATION

In a power plant, a generator rotates three different conducting loops at the same time. This is called ***polyphase generation.*** The three conducting loops are spaced exactly 120 degrees apart inside the generator. These conducting loops are commonly called ***phases*** or legs. The three phases are "out of step" along the sine wave. While one phase is positive, the second is negative, and the third is at zero. This three-way positioning (positive, negative, zero) is continuous as each loop rotates inside the generator. The three phases take turns changing polarity from positive to negative to zero. Polyphase generation produces alternating current in each of three phases that are "out of step" with each other. See Fig. 19-40.

The Greek letter phi (ϕ) is often used to abbreviate the word "phase." On a ***schematic*** (electrical circuit diagram) the letter L ("Line") is used with a number to help identify each phase (L_1, L_2, L_3). A potential difference exists between any two "hot" wires, because the polarity is different. The normal color code for these hot wires is black or red. However, they can be any color except white or green. See Fig. 19-41.

Each hot wire has the same voltage, but is different in polarity. Electrons flow according to polarity, but a voltage exists on each wire. Therefore, the potential difference between any two hot wires is additive (120 + 120 = 240).

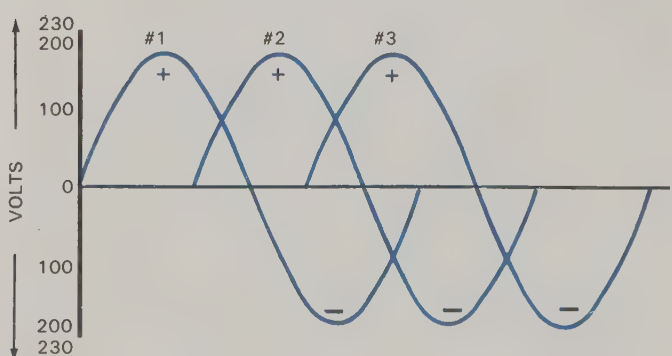


Fig. 19-40. In polyphase generation, the three loops (and thus the three phases), are 120° apart, as shown by the sine waves.

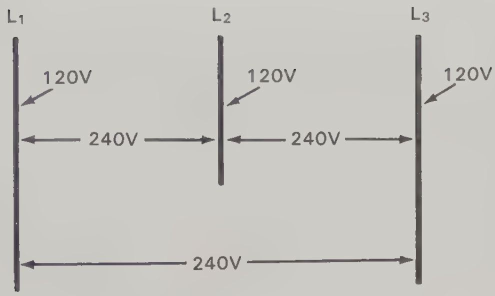


Fig. 19-41. In a three-phase system, voltage between any two wires is additive because the wires have different polarities.

SINGLE–PHASE

Many electrical devices are designed for connection to all three hot wires, and are called ***three-phase loads***. Other devices are designed to operate with just two hot wires from a three- phase system. These loads are called ***single-phase.*** Again, the voltage between the two hot wires is additive. The term *two-phase* is never used, because it refers to an older method of power generation that is no longer used. Voltage higher than 120V can be obtained only by using two of the three phases.

Many electrical devices operate with just one hot wire from a three-phase system and a second wire called the ***neutral.*** This method is also called single-phase, because only one hot wire is used. A potential difference exists because the hot wire contains voltage and polarity, while the neutral wire is zero voltage.

NEUTRAL WIRE

The earth is a gigantic mass of elements and compounds that serves as an excellent conductor of electricity. Damp soil is a better conductor than dry soil. The earth is always at ***zero potential*** (no voltage) and can be used to complete an electrical circuit.

The neutral conductor has white or gray insulation and is connected to the earth (***grounded***). This connection to earth is often made from the transformer on the utility pole to a solid copper rod driven eight feet into the ground. This copper rod is called a "grounding electrode." See Fig. 19-42.

This grounding of the neutral wire provides a pathway for electrons traveling to and from the earth. The neutral wire has zero voltage because it connects directly to ground. The neutral wire should not be broken, and is never fused. The electrical symbol for the neutral wire is N. The neutral wire is used as a current carrying conductor, but has no voltage. A potential difference exists between the neutral wire (no voltage) and any black or red ("hot") wire with 120 volts. See Fig. 19-43.

The ***National Electrical Code (NEC)*** refers to the neutral conductor as the grounded conductor. Another wire (*green* in color) is reserved as the grounding conductor. These two wires serve entirely *different* purposes

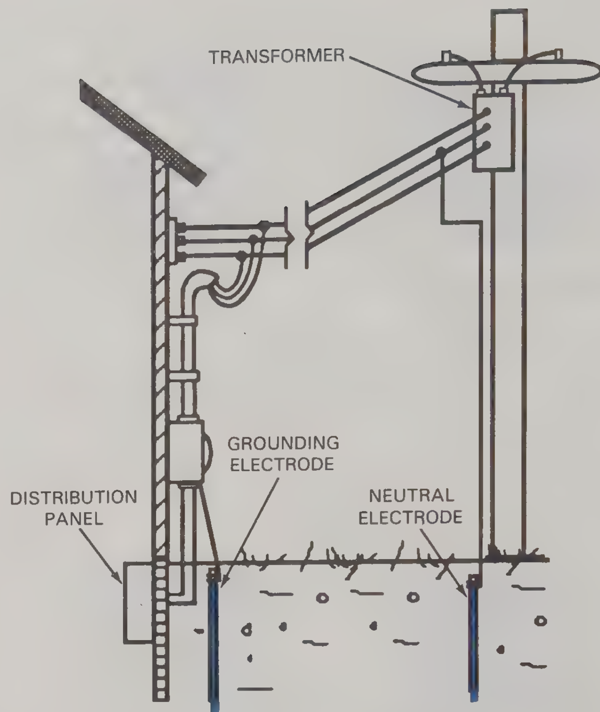


Fig. 19-42. A copper rod, driven 8 feet into the earth, is used to ground the neutral wire of an electrical system. A separate safety ground is connected to busbars in the distribution panel.

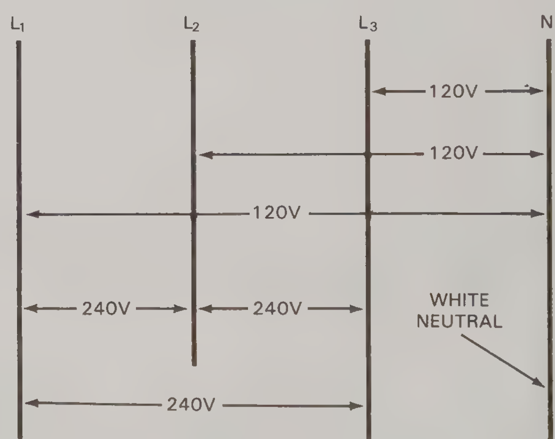


Fig. 19-43. A potential difference of 120V exists between the neutral and any of the hot wires.

and should never be confused. The purpose and proper use of the grounding conductor is explained later.

Single-phase loads designed to operate on 120 volts require the use of one hot (black) wire and the grounded neutral (white) conductor. The black conductor supplies electrons and voltage, and the white conductor supplies electrons at zero voltage. This provides a potential difference, so electrons are able to flow back and forth between the black and white wires.

Current flowing in the hot leg also flows in the neutral. When the load is operating, an amperage reading can be obtained from either conductor. See Fig. 19-44. The voltage and energy are used up by the energy conversion

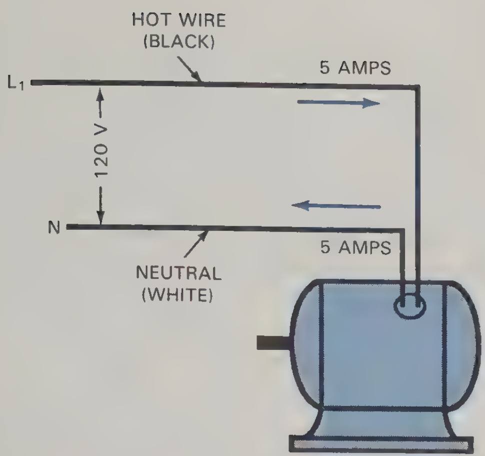


Fig. 19-44. Current flowing in the black wire also flows in the white wire. When the load is active, an amperage reading can be obtained from either wire.

device (load), so the neutral wire remains at zero voltage. If either wire is disconnected from the load, the potential difference is removed and electrons cannot flow.

Some single-phase loads are designed to operate on 240 volts. These loads require the use of *two* hot wires having 120 volts each (no neutral). The voltage between the two hot wires is additive (120V + 120V = 240V). The two hot wires have the *same* voltage, but *opposite* polarity. This opposite polarity (negative/positive) provides the necessary potential difference. This is called single phase (1F), but the *higher voltage* can only be obtained by using two different hot wires. See Fig. 19-45.

SAFETY GROUND

The equipment grounding conductor is a wire that was added for safety purposes, and is often called the earth ground or ***safety ground.*** This grounding conductor is *required* by the National Electrical Code on all new electrical systems. The color code for this wire is green, or it can be bare (uninsulated) copper. The symbol for the safety ground is shown in Fig. 19-46.

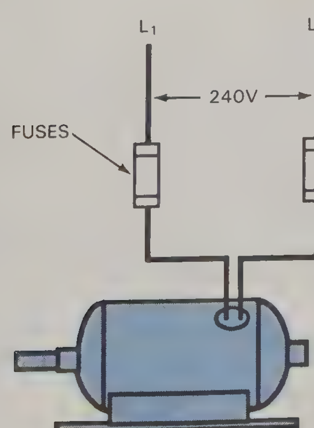


Fig. 19-45. A 240V single-phase motor, like this one, uses *two* hot wires (but no neutral).

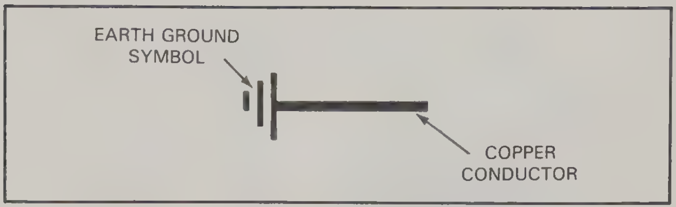


Fig. 19-46. A triangular symbol is used to indicate the safety (earth) ground on wiring diagrams.

Safety grounding conductors are connected to a busbar located inside the distribution panel. A ***busbar*** is a metal bar that serves as a common connector. It has multiple screws for connecting wires to it, and is securely bonded to the distribution box to obtain good metal-to-metal contact.

For residential wiring systems, the equipment grounding conductor (green) and the neutral conductor (white) share the same grounding busbar. The two busbars located inside the distribution center (breaker box) are connected together, Fig. 19-47. This is the only place where the neutral and safety ground are joined together.

The grounding busbar *must* be connected to a grounding electrode, also called a "grounding rod." The grounding rod is a solid copper rod driven eight feet into the ground to make good contact with moist earth. See Fig. 19-48. Consult your local electrical inspector or the NEC regarding approved grounding techniques.

Commercial and industrial electrical systems require complete separation of the grounding electrode from

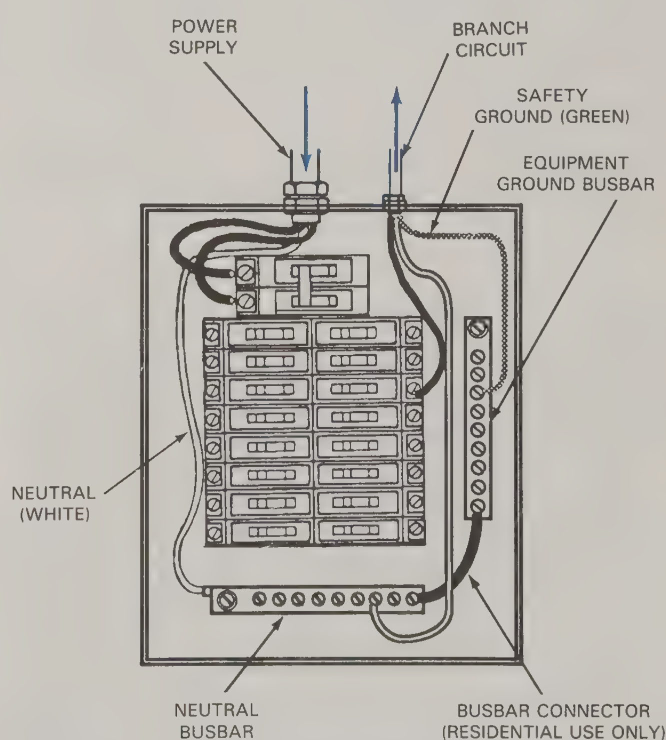


Fig. 19-47. For residential installations only, the neutral and equipment grounding busbars are connected together. They are both connected to a grounding electrode.

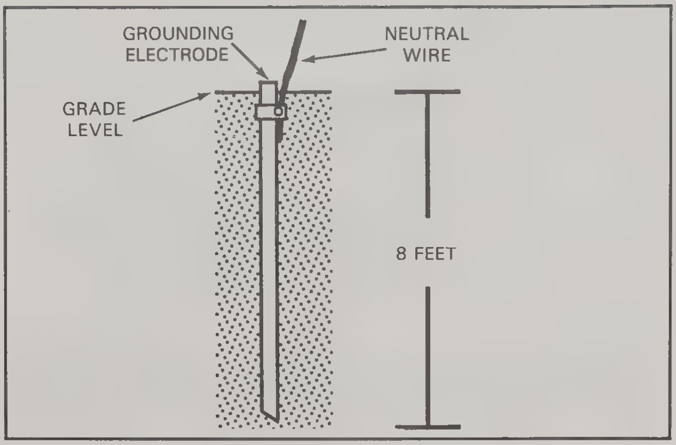


Fig. 19-48. The grounding rod, or electrode, is driven at least eight feet into the earth to make sure that it contacts moist ground.

the neutral electrode. As shown in Fig. 19-42, the neutral is grounded at the utility pole transformer. A separate grounding electrode is required for the equipment grounding conductor. This grounding electrode must be installed at the site.

The main switch gear (distribution panels) of commercial installations are equipped with separate busbars, Fig. 19-49. The equipment grounding busbar is often connected to the steel beams used in constructing the building. These beams serve as a grounding electrode.

Purpose of the safety ground

The safety ground conductor (green or bare wire) is *never* connected into the normal electrical circuit. This conductor serves as a "safety valve" when a malfunction occurs in the electrical equipment. The safety ground wire is connected to the frame of a motor or appliance, as shown in Fig. 19-50.

Under normal conditions, the frame of a motor or appliance is safe to touch. Sometimes, an internal electrical problem may occur that permits electron flow to the frame. This is called a ***ground fault*** and makes the frame electrically live. Anyone touching the frame would receive a severe electrical shock. The human body would become a "load" by completing a circuit from the frame to ground, as shown in Fig. 19-51.

When a ground fault occurs, the safety ground wire provides an unbroken pathway for electrons to travel from the frame to the grounding electrode. This amounts to a "dead short," with a highly excessive current flow

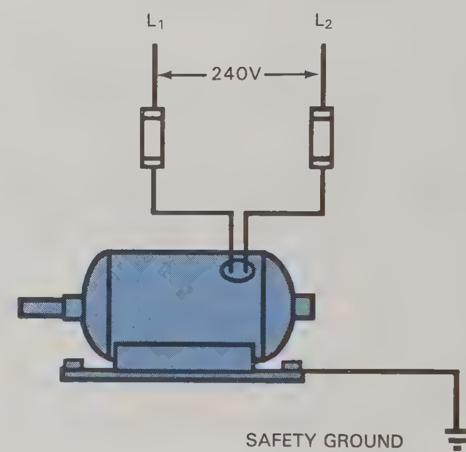


Fig. 19-50. The safety ground conductor is connected to the frame of a motor or appliance.

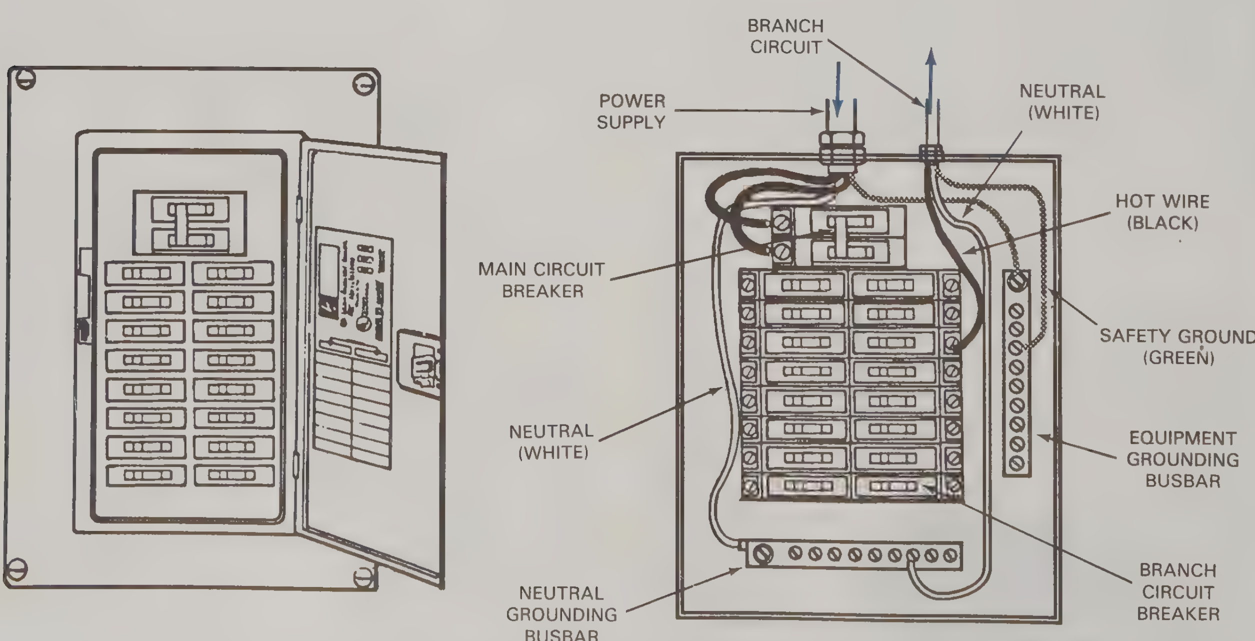


Fig. 19-49. In commercial installations, the neutral and equipment grounding busbars are connected to separate grounding electrodes. They are not connected together, as permitted in residential installations.

Fig. 19-51. Without a safety ground, if the frame of a motor should accidentally become electrically "live," touching the frame would make your body a load and complete the circuit to ground.

Fig. 19-52. A safety ground will provide a path to ground for electron flow, preventing an electrical shock if the frame is touched.

that should blow a fuse or trip a circuit breaker. The equipment grounding conductor provides an escape path for electrons when a ground fault occurs. See Fig. 19-52.

The safety ground wire is required by the NEC because it has proven very effective in preventing electrical injuries. The third (rounded) prong on plugs and the matching hole in receptacles are reserved for the safety ground connection. See Fig. 19-53.

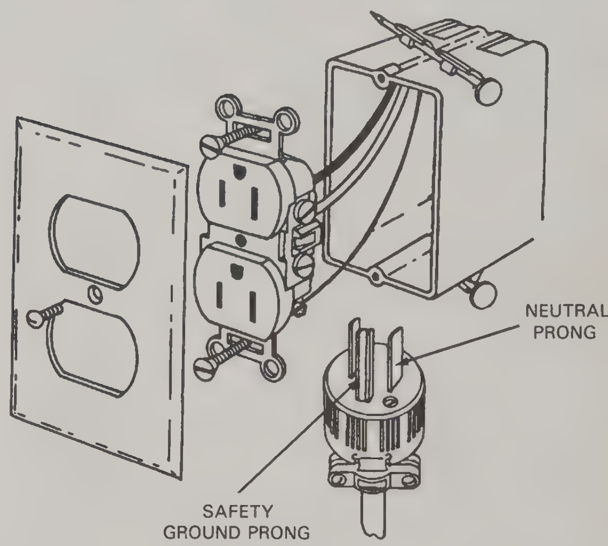


Fig. 19-53. The rounded prong on the plug and the matching socket in the receptacle are reserved for use by the safety ground. The receptacle should be installed with the ground uppermost, as shown, to help prevent accidental shorting across the hot and neutral prongs.

Using portable power tools

Special caution should be exercised when using portable power tools. These hand-held electrical devices can be dangerous if a ground fault occurs. Many power tools are constructed with metal frames. Such tools should have a 3-prong plug, with the metal frame connected to the safety ground. If the tool frame becomes electrically "live" due to a ground fault, the third wire (safety ground) will safely carry the current to ground. This third wire protects the operator from becoming a pathway to ground. The excess current flow should blow a fuse or trip a circuit breaker. Always use properly grounded power tools and connect them to properly grounded circuits.

Double-insulated tools. Many power tools do not have the third (safety ground) prong on the male plug. These devices are supposed to be "double insulated" to prevent a ground fault from the hot wire to the tool case. The case is often made of insulating plastic, to further protect the operator. A crack in the plastic case, however, can permit moisture to enter the insulation and defeat its purpose. Always examine such tools for cracks or damage. Never use a tool having a damaged case, or where the third prong has been removed.

Adaptors

Many old-style wall receptacles are of the two-prong type. These receptacles will not accept a 3-prong plug because they do not have the safety ground feature. A three- to two-prong *adaptor* is often used to connect a hand tool to these receptacles. For proper protection from a ground fault, the green safety ground wire *must* be connected to a suitable ground. The green wire from the adaptor is intended to be fastened under the screw on the receptacle cover plate. See Fig. 19-54.

This procedure assumes the receptacle box is properly grounded. However, most two-hole receptacles are *not* grounded, so ground fault protection is lost. Always use your voltage tester to determine if the receptacle is properly grounded. Zero voltage between the hot wire and a metal cover reveals no safety ground. A 120-volt reading between the hot wire and the metal cover indicates a good safety ground. See Fig. 19-55.

If the receptacle box is not grounded, use another piece of wire to connect the adaptor's green wire to a good ground. This extra precaution to properly connect

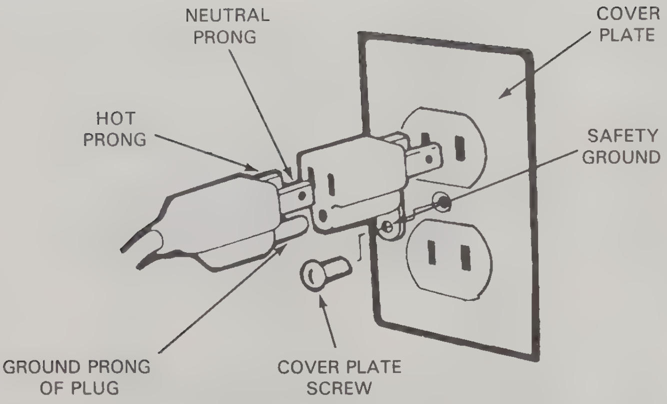


Fig. 19-54. When a three- to two-hole adaptor is used with a portable power tool, the green safety ground must be connected to a good ground. If the receptacle box is grounded, the safety ground tab or wire should be connected to the screw on the cover plate.

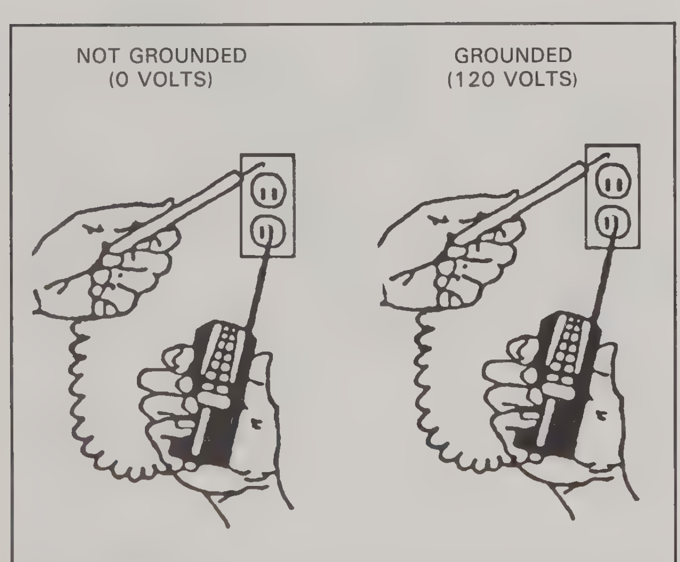


Fig. 19-55. Never assume that a receptacle is grounded. Check for voltage between the hot wire and the cover plate.

the safety ground may save your life if the power tool becomes "shorted" to the metal case.

Ground prong position

A recent NEC ruling requires that receptacles be installed with the ground connection at the *top*. If mounted sideways, the neutral prong should be on top. This change was made to prevent metal objects from falling between the plug and receptacle and contacting the hot wire.

The safety wire (green or bare copper) travels unbroken from the receptacle directly to the busbar inside the distribution panel. This busbar is directly connected to a grounding electrode. The neutral wire and the safety ground wire each have continuous zero voltage, but serve entirely different purposes. Never substitute the safety ground for the neutral wire, because dangerous conditions will result.

Many commercial and industrial applications require all electrical wires to be installed inside metal piping, called ***conduit.*** The metal pipes and metal enclosures are securely bonded together at each connection. This metal-to-metal pathway is often used as the safety ground. This continuous run of metal pipes and enclosures must be connected to a safety grounding electrode. This method of providing an equipment ground is effective and is mandated by the NEC. See Fig. 19-56.

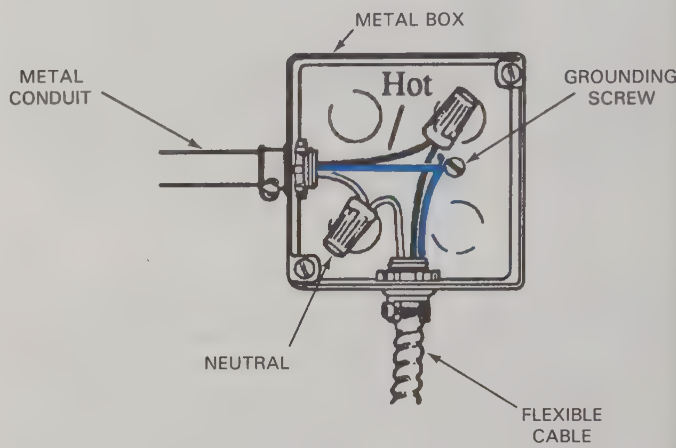


Fig. 19-56. Good metal-to-metal contact must be maintained for effective operation of the safety ground when metal tubing and boxes are used as the path to ground.

POWER CIRCUIT DEVICES

Circuits supplying electrical power to residential or commercial installations must include various types of devices. These includes *receptacles,* which allow easy connection and disconnection of equipment, and devices such as *switches* and *disconnects,* which control part or all of the circuit.

RECEPTACLE TYPES

Female outlet receptacles are used to provide a quick and easy connection to electrical power for equipment that has a flexible cord and male plug. As a safety feature, each plug and receptacle is sized and styled for a particular voltage and amperage. For example, a 250V plug cannot be inserted in a 120V receptacle. Likewise, a plug rated for 20 amperes cannot be plugged into a 15-ampere receptacle.

The shapes and styles of plugs and receptacles are standardized by amperage and voltage. Fig. 19-57 shows some of the many different types of plugs and receptacles.

SWITCH TYPES

As described earlier in this chapter, the purpose of a switch is to control the flow of electrons to one or more electrical devices. All switches contain one or more sets

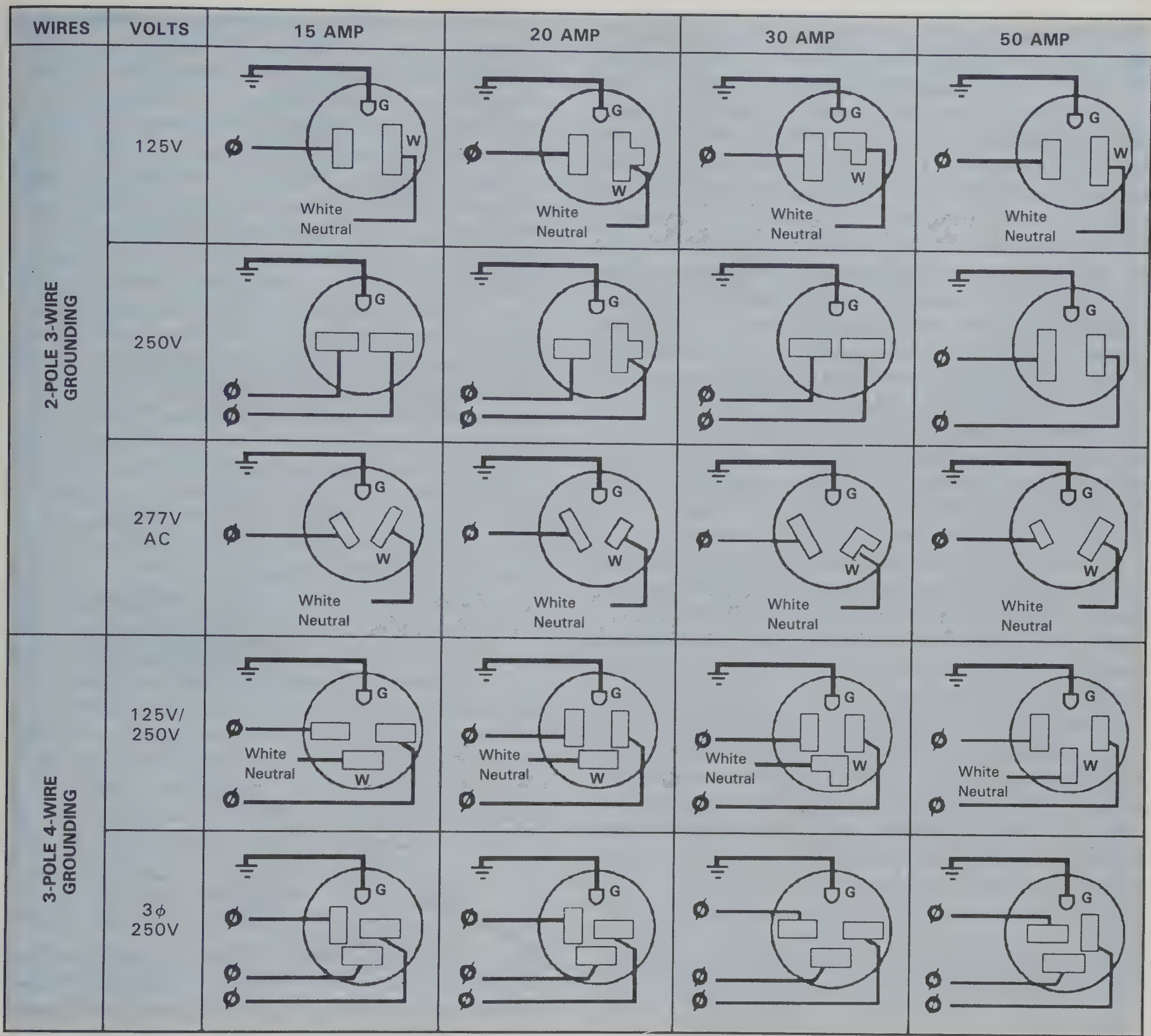


Fig. 19-57. Each type of plug and receptacle is sized and styled for a particular voltage and amperage. Some of the many types are shown here.

of ***contacts*** that are opened or closed by the movement of a ***pole.*** A switch may contain one or more poles. Movement of the pole is called the *throw.* This terminology is used to describe the operation of switches.

Switches are rated to operate within a maximum voltage and amperage. These ratings *must not* be exceeded. Switches for use in residential circuits are commonly rated: 125 volts at 10 amperes, or 250 volts at 5 amperes. Special-purpose switches may be rated for smaller or larger voltages and amperages.

The common household light switch is a ***single-pole, single-throw (SPST) switch.*** It has one pole and *makes* (closes) or *breaks* (opens) one contact. The operation of an SPST switch, in its simplest form, is illustrated in Fig. 19-58.

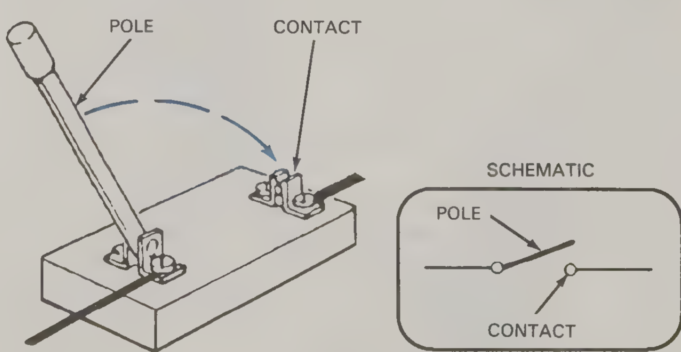


Fig. 19-58. The single-pole, single-throw switch (like the knife switch shown here) is the simplest type. It is either on or off. The common household light switch uses a toggle mechanism, but operates on the same principle: it either makes or breaks a contact.

WARNING: Household wiring methods often violate wire color codes. The white wire often may be used as the "hot" wire for connecting switches in a circuit. Indoor residential wiring is often done with nonmetallic cable, which is an insulated covering around two insulated #12 solid wires (one black and one white). The safety ground wire is bare copper. Because the cable has only two colors, the black and white wires are used to connect the switch in the hot leg to the light, as shown in Fig. 19-59. *Never* assume that the white wire is a *neutral:* when a black wire and a white wire are connected, the white wire becomes "hot." Color codes are not mandated and are often ignored. For safety, always check with a voltage tester before working on any wiring.

A ***single-pole, double-throw (SPDT) switch*** has one pole and operates two contacts, as shown in Fig. 19-60. One contact is normally open (NO) and the other contact is normally closed (NC), so there is no "off" position on this switch. Movement of the pole causes the NC contacts to open and the NO contacts to close.

A ***double-pole, single-throw (DPST) switch*** has two poles and a contact for each pole. Both contacts are either open or closed. This makes it possible to open or close *two* circuits at the same time. This switch is often used to control both hot wires on a 230V, single-phase circuit. See Fig. 19-61.

A ***double-pole, double throw (DPDT) switch*** has two poles and two contacts for each pole. Power supply must be connected to the poles. This switch makes it possible to control a variety of loads from one location. Two contacts are always closed and two contacts are always open. See Fig. 19-62.

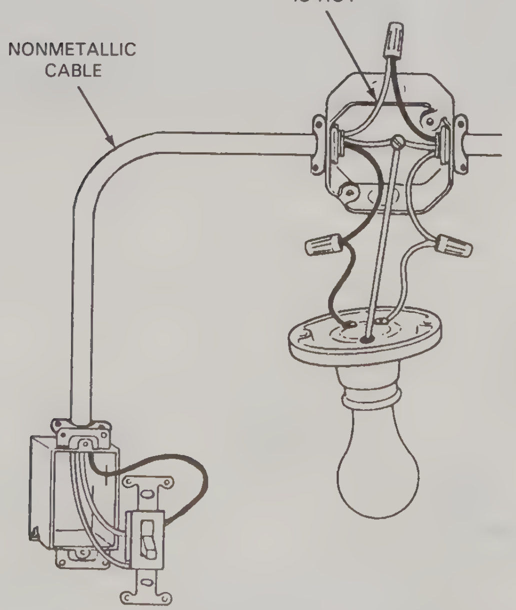


Fig. 19-59. When nonmetallic two-conductor cable is used in residential wiring, a white wire can sometimes be ''hot.'' Never assume that a white wire is neutral. Always use a voltage tester to check any wires before working on them.

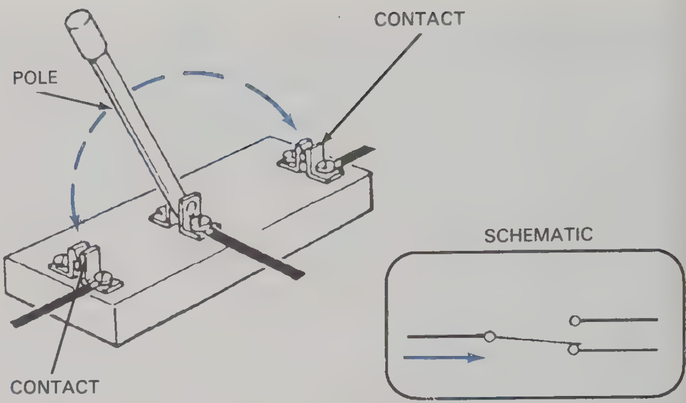


Fig. 19-60. On a single-pole, double-throw switch, the pole moves from one contact to another. One contact is normally open (NO); the other normally closed (NC).

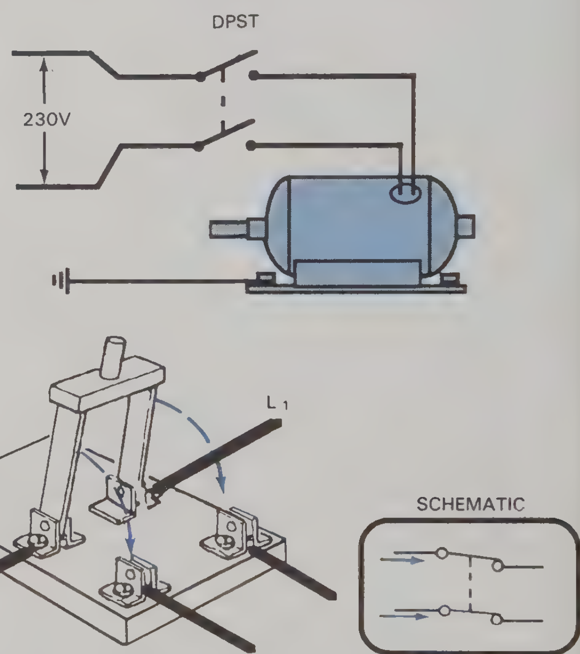


Fig. 19-61. A double-pole, single-throw switch can control two circuits, or both hot wires in a 230V circuit.

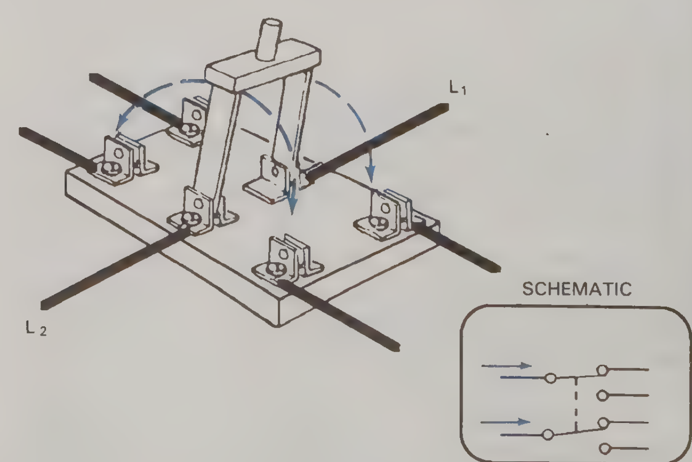


Fig. 19-62. A double-pole, double-throw switch can control a variety of loads. Two of the contacts are normally open (NO) and two are normally closed (NC).

DISCONNECTS

Disconnects are heavy duty, manually operated contacts used for disconnecting large loads from the power source. Disconnect switches are normally located close to the load for quick and easy access. A disconnect normally has a three-pole switch mounted inside a metal enclosure. All three switches are simultaneously controlled by the manually operated handle, Fig. 19-63.

When the disconnect includes fuses, it is called a *fused disconnect*. The power supply (***line voltage***) is connected to the terminals located in the top of the box. The switches are located between the power supply and the fuses. The load is connected to lugs provided at the bottom of the fuses. This procedure permits safe replacement of fuses when the switches are open. See Fig. 19-64. Always use a voltage tester to be certain all switches open properly. Even though the switches are open, use an insulated fuse puller when removing or replacing fuses.

Disconnect switches are rated and sized for a maximum amperage (such as 30, 60, or 100) and voltage. Each size disconnect requires a different size fuse. The fuse holders are designed to prevent use of too large a fuse. For example, a 60 ampere fuse will not fit a disconnect designed for 30 ampere service.

Do not open the disconnect switches when the load is operating. Always stop the load before operating the disconnect switches. Under certain conditions (such as a short circuit), a sudden inrush of extremely high current could cause the disconnect box to explode. Always operate the disconnect handle with the left hand, and stand to the side away from the box in case of malfunction.

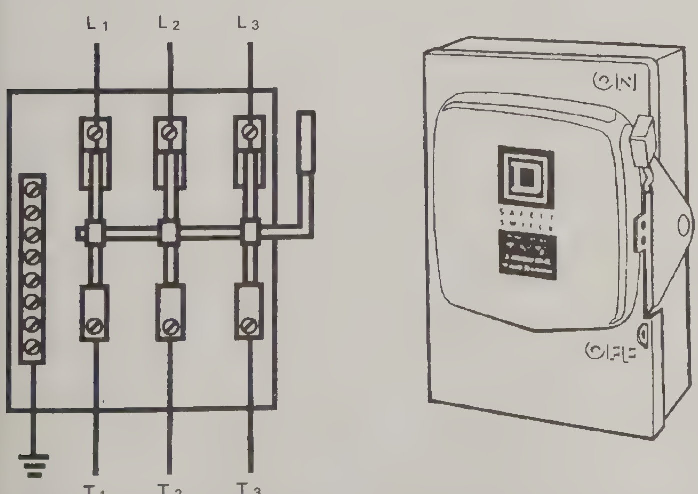


Fig. 19-63. Disconnects allow large loads to be quickly and easily disconnected from the power source. They are manually operated, heavy duty contacts. (Square D)

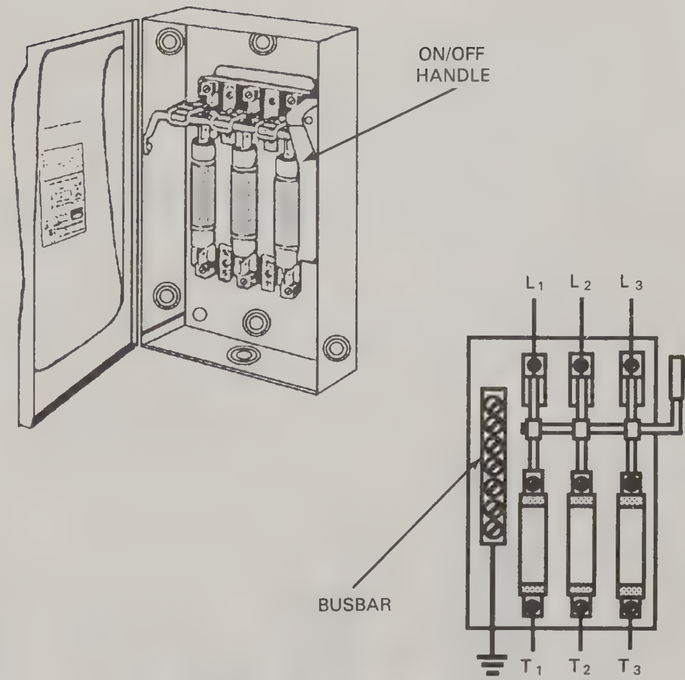


Fig. 19-64. In a fused disconnect, each line has a fuse located below the switch. An insulated fuse puller should be used to remove and replace fuses.

SUMMARY

Electricity is a form of energy involving the movement of electrons from one atom to another. Electrical energy can be converted to other forms of energy. Useful work is accomplished by forcing electrons through a load (resistance) that converts electrical energy to another form of energy.

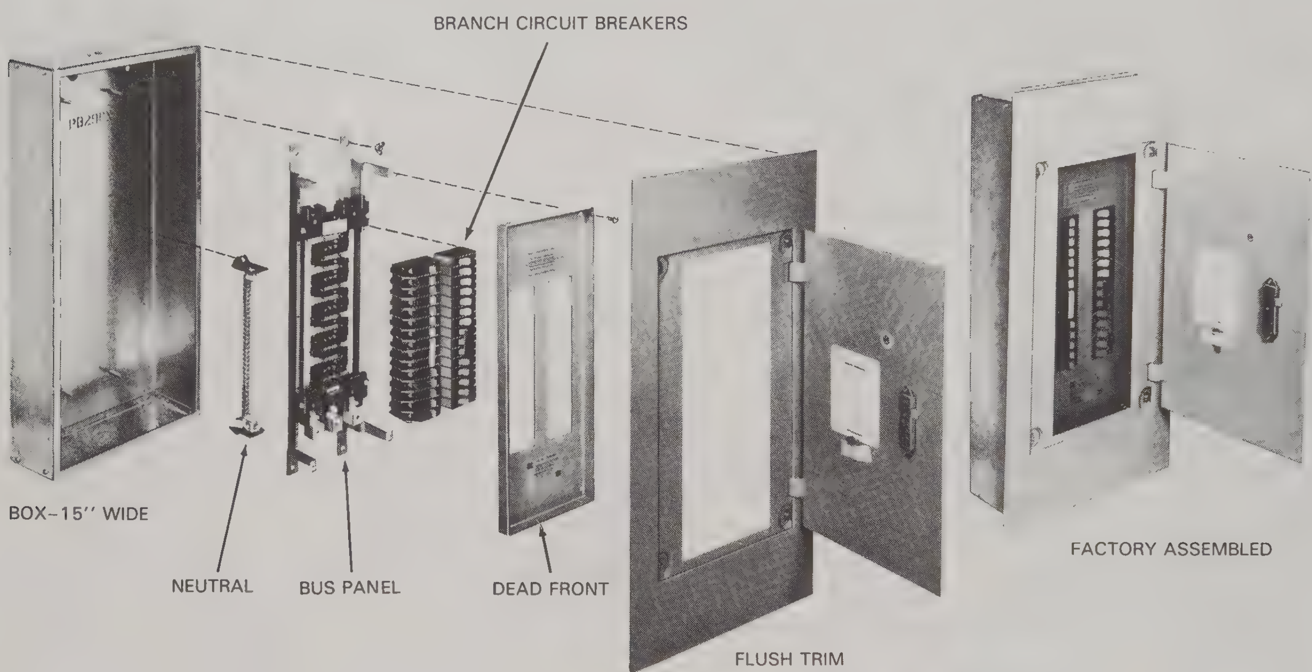
Conductors are used to provide the necessary supply of electrons, and to serve as a pathway for electrons through an energy conversion device, or load. Electrons cannot follow a path (circuit) unless it is complete and provides a difference in potential. Switches of various types control the flow of electrons by opening and closing one or more circuits. A safety ground is used to prevent possible shocks by providing a "safety valve" path to ground. Portable electric power tools must be properly grounded for safety.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. The movement of free electrons is called _________.
2. Electromotive force (emf) is measured with a _________.
3. Amperage is measured by using an _________.
4. True or false? Resistance is used to convert electrical energy to another form of energy.
5. An ohmmeter is used to check for _________, _________, and _________ circuits.
6. Name three good conductors of electricity.
7. Electric power (the ability to do work) is measured in _________.
8. What is the most commonly used wire size?
9. Are switches always connected in series or in parallel?

10. What is a load?
11. True or false? Loads in a circuit are always connected in parallel.
12. When connected to an open circuit, an ohmmeter will read ________.
13. Which meter is used to measure resistance?
14. In a short circuit, ________ current flows through a wire.
15. Name two devices that are used for protection against short circuits.
16. What color is the neutral wire?
17. What five items will determine the ampacity of a conductor?
18. When connecting a load to a voltage source, a minimum of ________ conductors must be used.
19. An voltmeter connected between the hot contact of a receptacle and the metal cover plate shows a reading of zero volts. Is the receptacle grounded?
20. True or false? All four contacts can be closed at the same time in double-pole, double-throw switch.



A 240V load center used for commercial installations. Exploded view shows components assembled into completed load center at right. (Cutler-Hammer)

Chapter 20

POWER TRANSMISSION AND CIRCUITS

After studying this chapter, you will be able to:
- *Select and connect transformers.*
- *Identify various common voltages and their uses.*
- *Size and use circuit protectors properly.*
- *Make good terminal connections.*

NEW WORDS

amperage interrupting capacity (AIC)	magnetic field
cartridge fuses	overcurrent
circuit protection devices	overload
conductors	oversizing
crimp	power factor
dead leg	primary winding
delta	reset
double-pole breaker	secondary winding
dual element	short circuit
full load amperage (FLA)	single-pole breaker
fuse	stinger leg
fusible element	terminal connectors
ground fault circuit interruptor (GFCI)	terminals
induced voltage	three-pole breaker
insulation	transformers
load center	undersized
	wire nuts
	wye

POWER TRANSMISSION

Electrical power is normally generated as three-phase, 60 Hz, alternating current at voltages up to about 26,000 volts. A step-up transformer then increases this voltage to 120,000 (or more). In transmission lines, high voltage reduces current flow ($P = I \times E$). This permits the use of smaller diameter wire over long distances. Power is often transmitted for hundreds of miles, using steel towers to support the wires. The three-phase, four-wire system (with grounded neutral) is used, and the grounded neutral line serves to ground the steel towers and protect them from lightning. See Fig. 20-1.

At various points along the transmission circuit, substations are located. There, step-down transformers reduce voltage to 40,000 volts for distribution through a particular region. Transformers at other substations *within* a region further step down voltage to 13,200 volts or to 4800 volts. Transformers for reducing voltage to individual homes and businesses are often located on utility poles, but may be at ground level in protective enclosures. The final voltage used by the consumer normally varies from 120 volts, single phase, to 480 volts, three-phase, depending upon the needs of the customer.

MEETING VARYING ELECTRICAL NEEDS

The distribution system can supply electrical power in various configurations to meet the different requirements of customers ranging from large industrial plants to individual households.

For commercial and industrial applications, three-phase alternating current is most common. Three-phase power supply is cheaper than single-phase, and provides other advantages. For example, three-phase motors do not require starting components, and offer better start and run characteristics. Three-phase is easier to understand and control. Easy access to 120V, single-phase, for lighting and receptacles is provided by

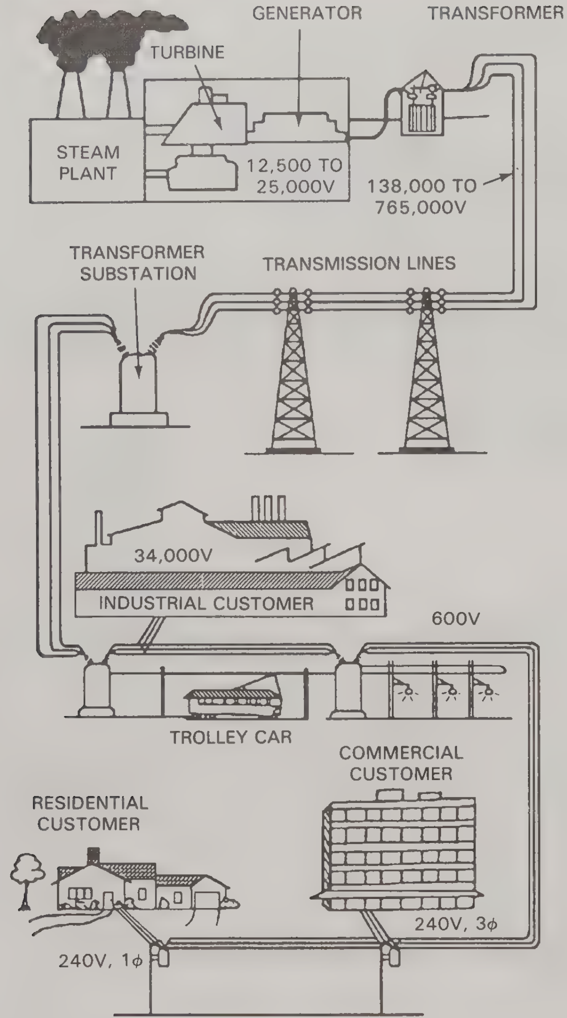


Fig. 20-1. The power transmission system steps up voltage to send electricity over long distances. Voltage is then "stepped down" to meet the needs of different users connected to the distribution system.

including the neutral wire. Fig. 20-2 illustrates a typical 230 volt, three-phase, four-wire system.

Three-phase motors require the use of all three "hot" wires (no neutral). It requires all three hot wires (L_1, L_2, and L_3) to obtain a three-phase supply; the voltage is measured between any two hot wires. Single-phase power is obtained from a three-phase supply by using just two hot wires, or one hot wire and the neutral. All voltmeters have two test leads that are used to check potential difference between any two hot wires, or from one hot wire to neutral.

An industrial customer, such as a factory, is supplied with a 480-volt, three-phase, four-wire system (three hot and one neutral). The safety ground (grounding rod) is installed at the site. Much equipment inside the factory is operated by 480V, three-phase motors. The fluorescent lighting is operated on 277V, single-phase (one hot leg and the neutral). See Fig. 20-3. A step-down transformer can be used within the plant to reduce the 480V, three-phase to 240V, three-phase. This provides additional options for use with smaller motors, incandescent lighting, or wall outlets.

A commercial customer, such as a supermarket, is supplied with 240-volt, three-phase, four-wire system (three hot and one neutral). The safety ground (grounding rod) is added at the site. The three hot wires are used to power refrigeration and air conditioning equipment. Some equipment in the bakery, meat department, and deli operate on 240V, single-phase, using two hot wires (and safety ground). By using one hot wire and neutral (with safety ground) 120V single-phase is obtained for lighting circuits and receptacles. The single-phase loads must be equally divided among the three hot wires to balance the load on all three phases.

Most residential units are provided with two hot wires and a neutral (240V, single-phase). The safety ground is installed at the site. See Fig. 20-4.

Some home appliances, such as the water heater and central air conditioning, require 240 volts for operation. These appliances require two hot wires and the safety ground. Other appliances, such as the clothes dryer and electric range, require both 240 volt and 120

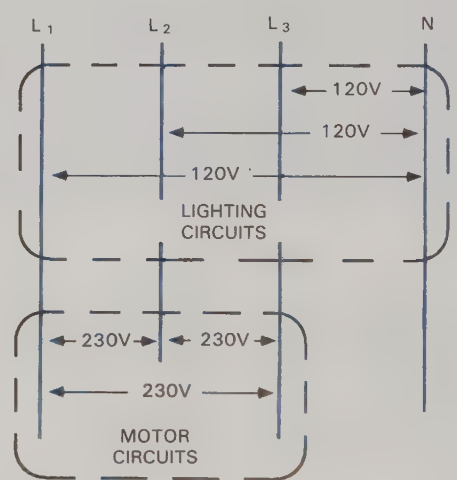


Fig. 20-2. Three-phase power is used for many commercial and industrial applications. Different hot and neutral wire combinations can provide various voltages.

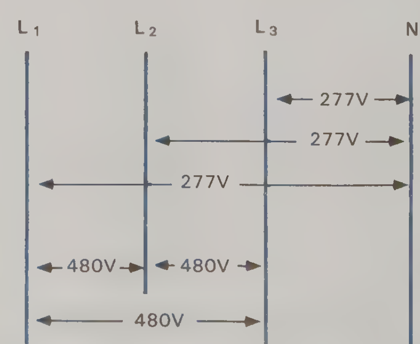


Fig. 20-3. A 480V, three-phase, four-wire system is generally provided for customers with large power needs, such as industrial plants.

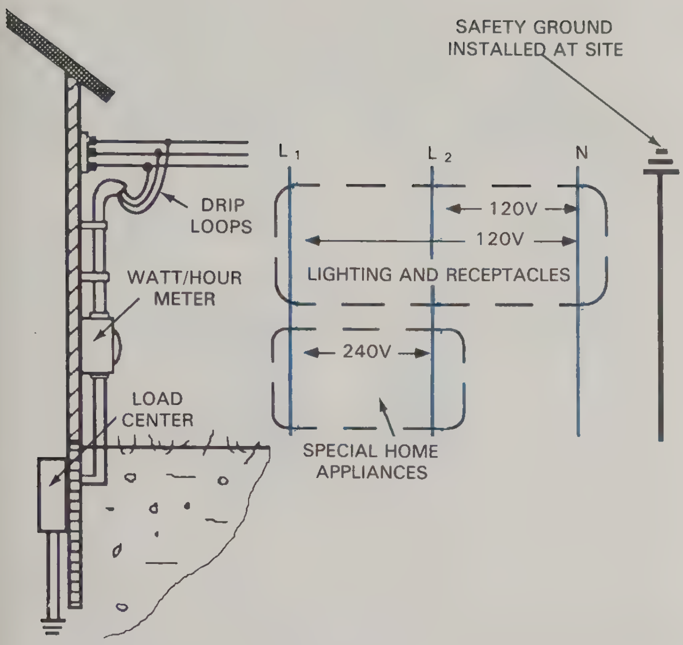


Fig. 20-4. A residential unit will typically be supplied with a 240V, one-phase, 3-wire system. The safety ground is connected to a rod driven into the earth at least 8 feet.

volt. Those *dual voltage* appliances require two hot wires, the neutral, and the safety ground.

Residential lighting and receptacle circuits call for 120-volt, single-phase connections. This is obtained by using one hot wire and the neutral, (and the safety ground). The various 120-volt circuits should be equally balanced between the two hot supply wires.

TRANSFORMERS

A chief advantage of alternating current is the fact that it can be generated at one voltage, transmitted at higher voltage, and then reduced to a lower voltage at the point of use. ***Transformers*** make it possible to increase (step up) or decrease (step down) the voltage. See Fig. 20-5. This flexibility is highly desirable and is used throughout the world for residential, commercial, and industrial electrical systems.

Transformers are 96–98 percent efficient. They have no moving parts. They require very little maintenance because of their simple, rugged, and durable construction. A transformer has two copper windings (coils) that are electrically separated from each other. These coils are wound around a core made of laminated soft iron sheets. The laminated core provides a circuit for the magnetic field. See Fig. 20-6.

Transformer operation is based on the principle that electrical energy can be transferred efficiently by magnetic induction from one winding to another. When an alternating current flows in the ***primary winding***, an alternating ***magnetic field*** is established in the laminated soft iron core. This induces an alternating current in the ***secondary winding.*** The magnetic field cuts across the turns of both windings. Therefore, the same voltage is induced in each turn of the two windings. The ***induced voltage*** in each winding is proportional to the number of turns in that winding.

Thus, voltage at the secondary (output) winding is determined by the number of coils or wraps in that winding, versus the number of coils in the primary (input) winding. Fewer coils in the secondary will produce a lower output voltage. This is called a step-down transformer. More coils in the secondary will increase output voltage. This is called a step-up transformer. See Fig. 20-7.

Electrical energy conversion devices (loads) are manufactured to tolerate a voltage variation of plus or minus 10 percent. However, many motors and other devices are limited to 5 percent variation. A transformer is often required to increase or decrease the supply voltage to match the load voltage specification. For example, a single-phase motor designed to operate on 230 volts cannot be connected to 208 volts. A transformer must be used to change the power supply from 208V to 230V. As shown in Fig. 20-8, the 208V power supply is connected to the transformer primary and the motor is connected to the 230V secondary.

Some single-phase transformers are manufactured to offer a choice of voltages. These are called multi-tap transformers. The windings may have three or more

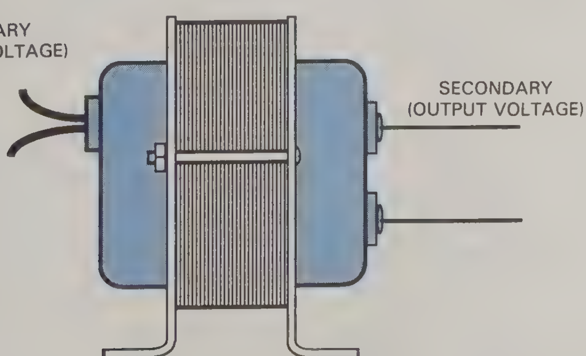


Fig. 20-5. A transformer is used to increase or decrease voltage. The electric power transmission and distribution system uses many transformers.

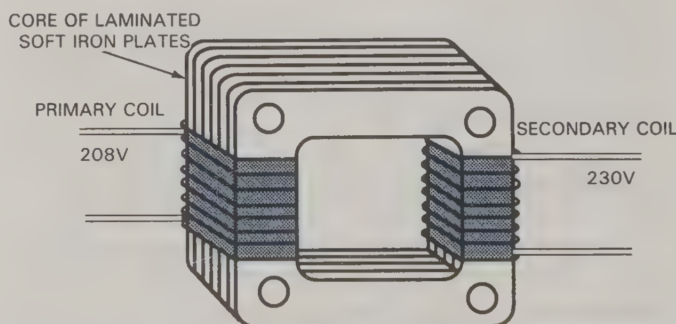


Fig. 20-6. Electrically separated windings transfer electrical energy through the iron core by means of magnetic induction. The differing number of turns of wire in the windings is responsible for the increase or decrease in voltage.

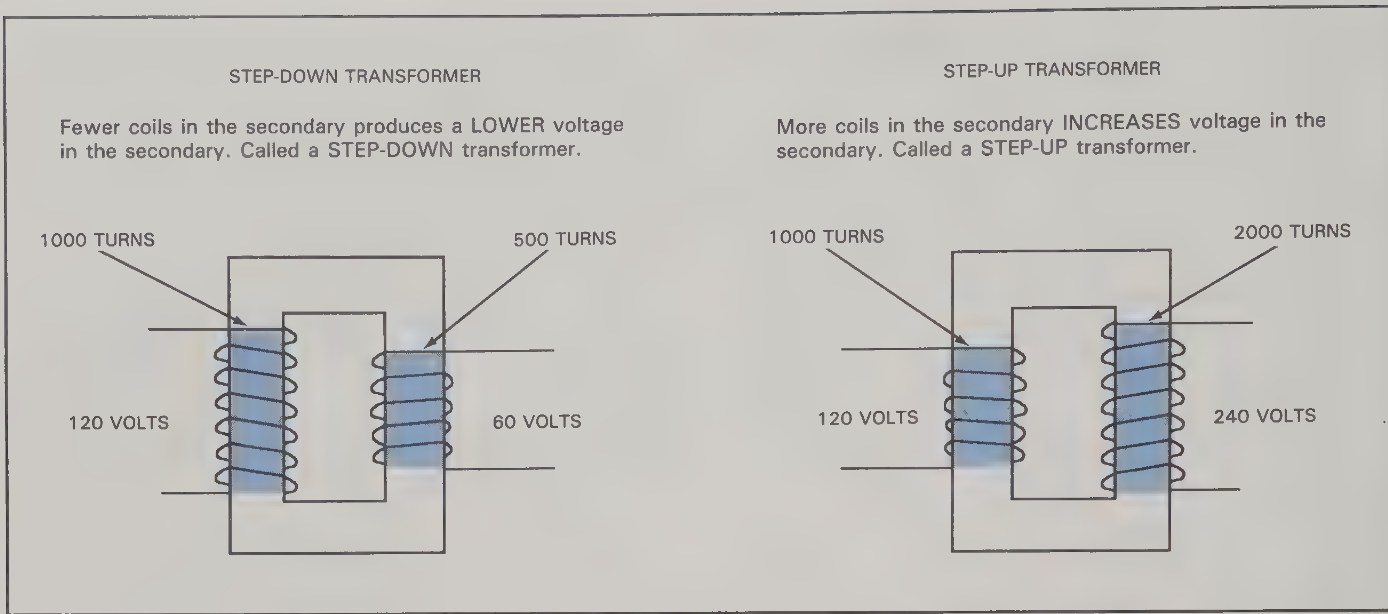


Fig. 20-7. Transformers can increase (step up) or decrease (step down) voltage.

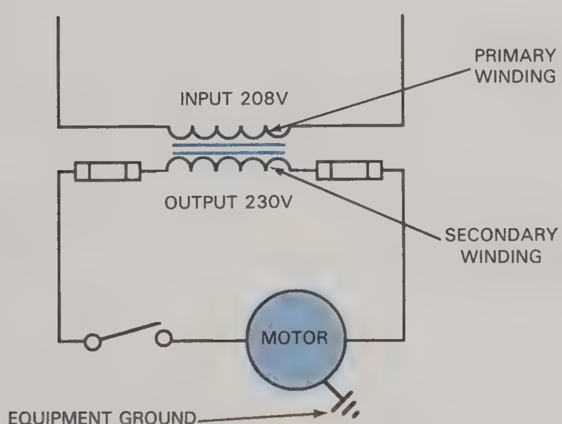


Fig. 20-8. A step-up transformer is used to increase input voltage to the correct level for a motor.

connections (*taps*), which make it possible to use different input voltages or to obtain different output voltages. Only *one connection* can be made on each winding at any time. The unused extra wires must be capped and sealed. Multi-tap transformers are convenient because one transformer can serve several different applications. A wiring diagram or instructions are always included on each transformer to assure proper connections. See Fig. 20-9.

TRANSFORMER SYMBOLS AND TERMINALS

The symbol for a single-phase transformer is shown in Fig. 20-10. Electrical schematics use this symbol, or some variation, to indicate a single-phase transformer. Three-phase transformers consists of separate insulated windings for the three different phases. These windings are on a three-legged core to permit establishing of three magnetic fields spaced 120 degrees apart.

Three-phase transformers can be of either the delta or the wye type. The ***delta*** is similar to a triangle (D), while the ***wye*** (sometimes referred to as "star") is similar to a letter "Y." See Fig. 20-10.

Transformer ***terminals*** are often labeled and tagged with letters of the alphabet combined with numbers. Standard practice is to tag the transformer primary terminals with H_1, H_2, H_3, etc. The secondary terminals are tagged X_1, X_2, X_3, etc. (X_0 is used to indicate the neutral terminal). See Fig. 20-11.

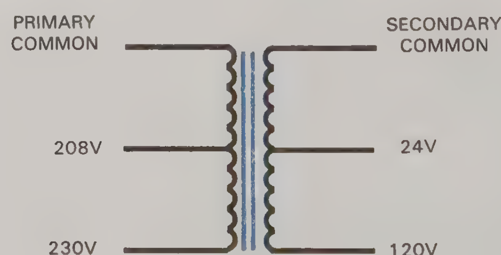


Fig. 20-9. Multi-tap single-phase transformers provide several possible connections on both the input and output sides. Only one voltage connection per side can be made at any one time: 208V or 230V input; 24V or 120V output.

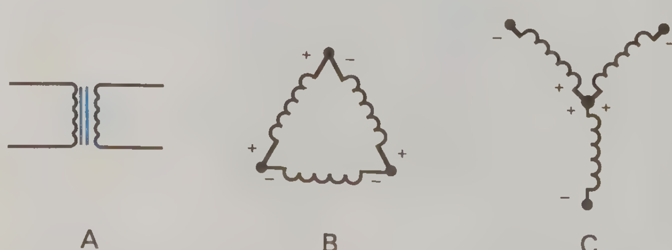


Fig. 20-10. Transformer symbols for use on electrical schematics. A–Single-phase. B–Three-phase delta. C–Three-phase wye.

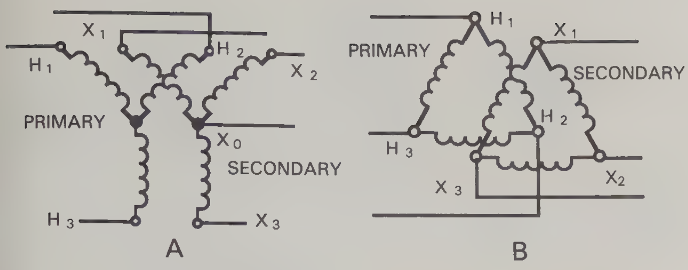


Fig. 20-11. Transformer terminals are identified by the letter "H" on the primary side, and "X" on the secondary side. A–Wye transformer. B–Delta transformer.

TRANSFORMER RATINGS

In addition to the desired primary and secondary voltages, transformers are selected by the *amperage* the secondary can safely carry. The transformer secondary must be able to carry more than the minimum required amperage to accommodate the load(s) connected to it. ***Oversizing*** the transformer by 125 percent helps protect it from becoming overloaded.

Single-phase transformers are rated by VA (volts x amps) at the secondary. (VA = Volts x Amps = E x I.) For example, a 48 VA transformer that has a 24V secondary will safely carry 2 amperes of current (24V x 2A = 48 VA).

What size transformer should be selected if the secondary is to carry 20 amps at 230 volts? At minimum, 4600VA (230V x 20A = 4600VA). To protect the transformer from overload, a 125 percent oversizing is recommended, so a transformer rated at approximately 6000VA should be chosen.

Transformers ratings of over 1000 VA are normally given in KVA, (K = 1000). Therefore, the rating for a 6000 VA transformer would be given as 6 KVA. Transformers with 1 KVA or higher ratings are always grounded by a separate cable or bus to a grounding electrode. This grounding electrode may be the steel of the building or a rod driven into the earth. A transformer rated under 1 KVA may be grounded to the cabinet or the conduit serving it. The cabinet or conduit is then connected to the grounding electrode.

An overloaded or ***undersized*** transformer will burn out because the secondary coil cannot carry the current. A minor overload causes a slow burnout and a large overload causes a quick burnout. Transformers should be protected with fuses. *Oversizing* a transformer does no harm, but is more expensive. When replacing a burned-out transformer, always check amperage in the secondary circuit to be sure there is adequate capacity.

THREE-PHASE TRANSFORMERS

As noted earlier, three-phase transformers can be of either the wye or the delta type, although the wye (or star) is most popular. Three-phase transformers have a better ***power factor*** (computed by multiplying VA x 1.73 and converting the answer to KVA) than single-phase transformers.

Because electricity is produced in three-phases (called polyphase generation), a variety of transformer types (wye, delta, wye-delta, or delta-wye) must be used to produce the secondary voltages that will match customer needs. Loads and other electrical equipment are connected to the transformer secondary *must* match the voltage supplied by the transformer. Fig. 20-12 shows some of the voltages that are possible and are commonly used.

Some older installations use a "high leg" system from a three-phase delta transformer. Voltage readings from two of the hot legs to neutral will read 115V. However, a reading from *one* of the hot legs to neutral will register 208V. This higher-voltage wire is often called the ***stinger leg*** and cannot be used for 115V circuits. The stinger leg normally uses orange-colored wire, and should be tagged or marked for easy identification. See Fig. 20-13.

Another basic system is the ***dead leg*** system from a three-phase delta transformer. One corner of the delta transformer is grounded and called the dead leg. A reading of 240V can be obtained between any two phases (including the dead leg). A voltage reading from the dead leg to ground is zero volts. See Fig. 20-14.

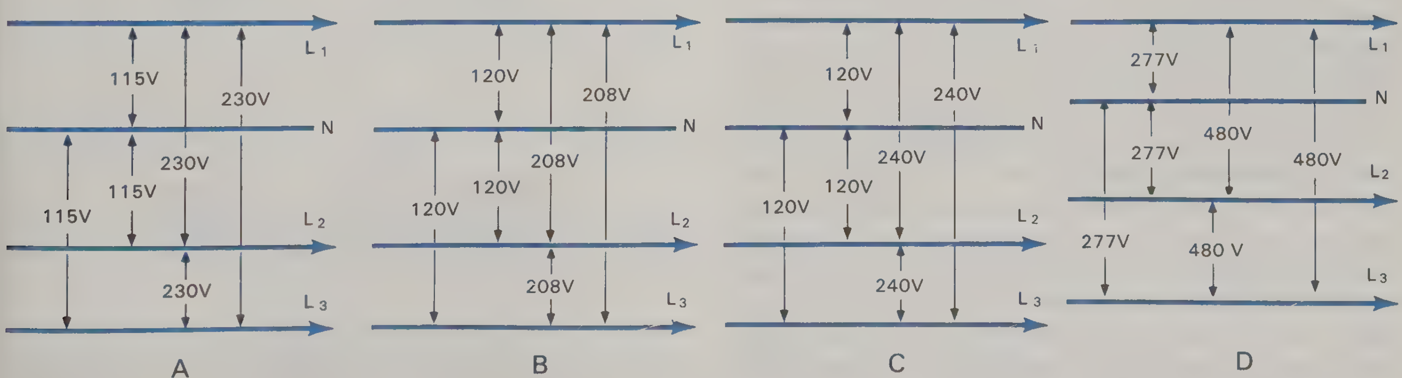


Fig. 20-12. Transformers can provide a variety of voltages to meet differing customer needs. A–230V, 3-phase, 4-wire. B–208V, 3-phase, 4-wire. C–240V, 3-phase, 4-wire. D–480V, 3-phase, 4 wire.

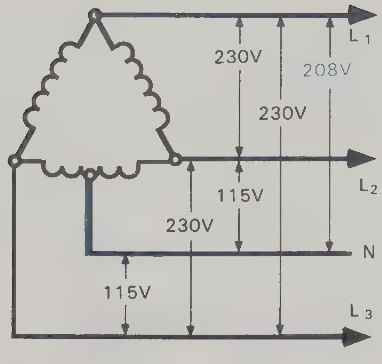


Fig. 20-13. A 230V, 3-phase, 4-wire system with a "high leg" will have one leg that provides higher voltage. In this case, the L1 to neutral reading is 208V; readings from other legs to neutral are 115V. The high or "stinger" leg should be marked for ease of identification.

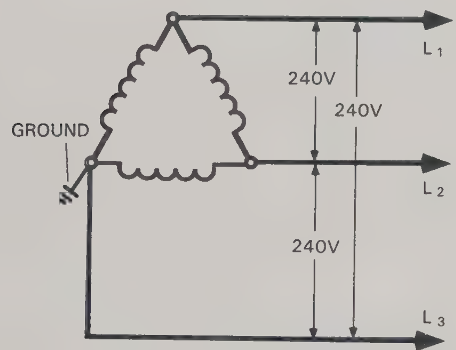


Fig. 20-14. A "dead leg" system has one leg grounded. Any two legs will provide 240V. The reading from the dead leg to ground is 0V.

OVERCURRENT

All conductors (wires) are sized to carry a limited amount of current without overheating. ***Overcurrent*** occurs when too much current flows through a wire. Overcurrent causes the wire to become hot, damaging or destroying the wire's insulated covering. Insulation damaged by overcurrent presents a serious hazard: exposed (bare) wire is dangerous to equipment and people. Overcurrent can be caused by a variety of electrical problems, such as loose connections, ground faults (short circuits), defective resistance, or too many loads.

Overcurrent in the form of an ***overload*** or short circuit is defined as "current in excess of the normal flow for a given circuit." Overloads can range between twice and ten times normal current. Typical causes of overloads are too many loads in the circuit, loose connections, and dry motor bearings. An overload is usually confined to the circuit wiring. A ground fault or ***short circuit*** occurs when electrons are permitted to travel unrestricted through a path with very low, or no, resistance. See Fig. 20-15. The resulting large overcurrent may exceed normal current by hundreds of times. High heat is generated rapidly and explosions may occur. A ground fault or short circuit is *very dangerous.*

CIRCUIT PROTECTION

Every electrical circuit must have some type of safety device, such as a fuse or a circuit breaker, to protect against overcurrent. Fuses and circuit breakers are manufactured in various shapes and sizes. They are designed to stop the flow of current when it exceeds safe limits. These ***circuit protection devices*** are rated in amperes and volts. Their amperage rating must not be greater than the ampacity of the wires being protected.

Fuses and circuit breakers must be able to interrupt the extreme overcurrent created by a short circuit. However, each device has an *overcurrent interrupting limit*, beyond which it can no longer interrupt current flow. If the overcurrent limit is exceeded, the device may violently arc or even explode and start a fire. This limit is called the ***amperage interrupting capacity (AIC)*** of the device. The AIC is much larger than the load current rating of a fuse or circuit breaker. The load rating is the current carrying capacity during normal operating conditions.

All overcurrent protective devices are labeled with their normal load current rating and AIC for a given voltage. The amperage interrupting capacity of most circuit breakers is between 10,000 and 20,000 AIC. Most fuses are rated about 200,000 AIC.

FUSES

The purpose of a ***fuse*** is to detect excessive load current and open the circuit before danger arises. It is standard practice to locate fuses in the main power supply and in each branch circuit. A blown fuse in a branch circuit helps confine the problem to a specific area. Fuses and circuit breakers are used to protect wires and equipment, not people. See Fig. 20-16.

How a fuse operates

Zinc is a metal that has moderate internal resistance to the flow of electrons and a rather low melting point. For these reasons, it is often used as the connecting link (***fusible element***) in a fuse. See Fig. 20-17. When excess current flows through the fuse, the link becomes over-

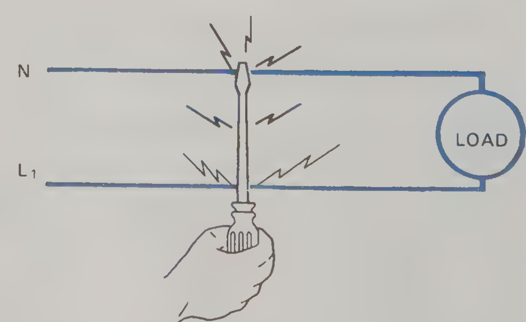


Fig. 20-15. Never work on a live circuit, since a slip of a screwdriver or other tool can easily cause a short circuit. The resulting high overcurrent can have painful or even fatal results.

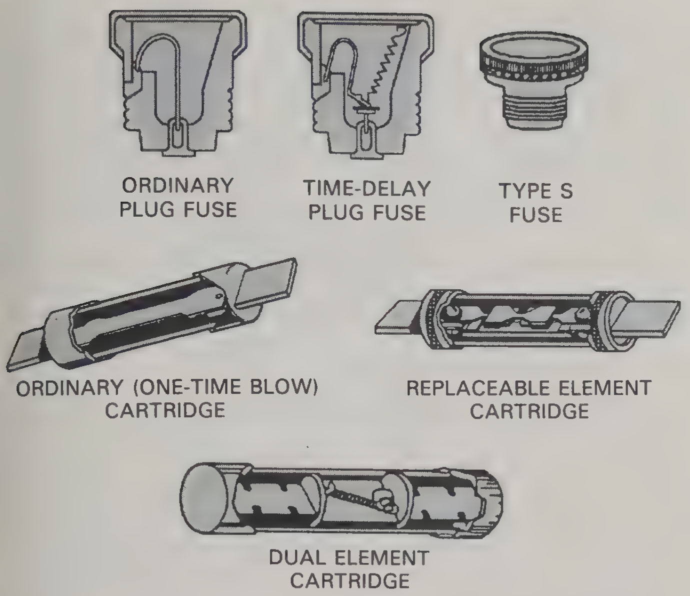


Fig. 20-16. Fuses have two basic shapes, plug and cartridge, but are available in many amperage ratings. Time-delay fuses allow short-duration overloads (such as a motor starting) without interrupting the circuit.

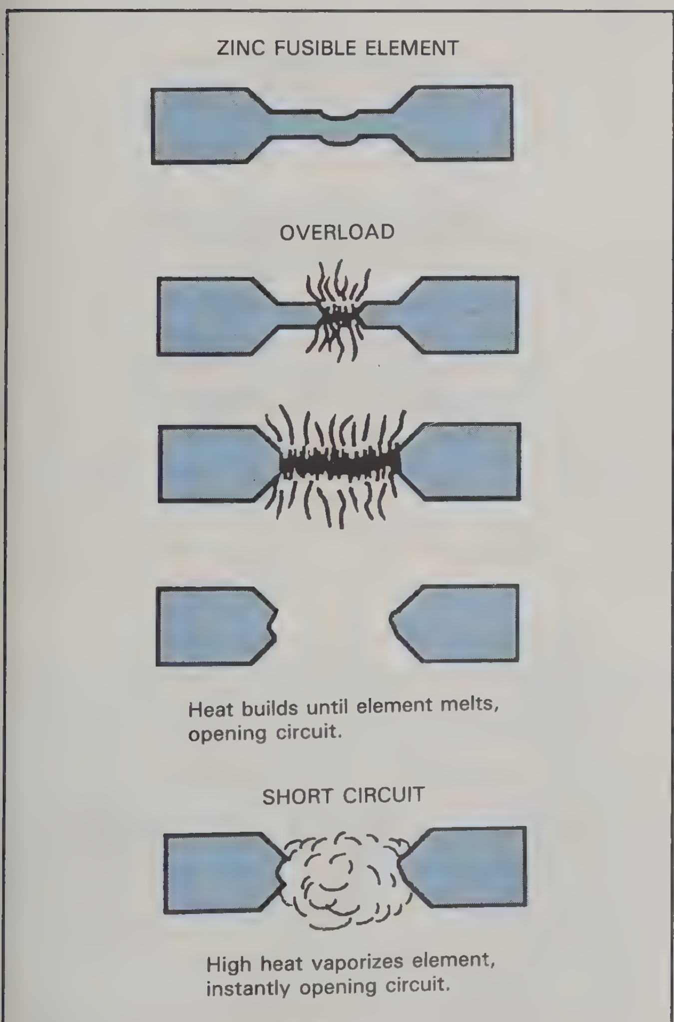


Fig. 20-17. The zinc element in a fuse reacts differently to overload and short circuit conditions.

heated and melts (blows). This opens the circuit and stops current flow.

The *amount* of excess current flow determines how fast the link melts. On a short circuit, the link is instantly vaporized. Overloads cause a slow buildup of heat, and the link melts slowly. A fusible link will open in one to 15 minutes on a 50 percent circuit overload. However, most fuses will withstand a 10 percent overload indefinitely.

Fuses are used to protect the wires and equipment against overloads and short circuits. Thus, a blown fuse indicates a serious circuit problem that must be corrected. The load amperage rating of a fuse must not exceed the ampacity of the feeder wire. Oversizing fuses is an invitation to disaster.

Plug-type fuses

Plug-type fuses (10A to 30A) are sometimes used for 120V circuits. Three different types fuses are available, Fig. 20-18.

Ordinary plug fuse. This type of fuse has no time delay; the link melts (blows) when the amperage rating is exceeded. This fuse is used to prevent overheating of wiring in the circuit due to excess current flow, which could cause a fire. The fuse should open the circuit before the wire becomes hot.

Time-delay fuse. The time-delay (***dual element***) fuse is designed to permit an overload of short duration, but to blow instantly if a short circuit occurs. Time-delay fuses are necessary when fusing a circuit containing an electric motor. They permit the momentary high starting current of the motor, which is about six times normal running current, without opening the circuit. The high current is very brief, but occurs every time the motor starts. As the motor achieves full speed, counter-emf (increased resistance) fully develops and current drops to normal running level.

An ordinary fuse used with a motor must be oversized to permit high starting current. However, this means that the fuse is too large to protect the wires during normal operation. If the fuse is sized for normal running current, it will blow every time the motor starts.

As shown in Fig. 20-19, the time-delay feature is accomplished by adding a spring and attaching one end of the link to a heat sink with a low-melting-point solder. When an overload occurs, heat is generated. If the condition continues long enough, the heat will melt the solder. The spring pulls the link away from the heat sink, opening the circuit. (If a short circuit occurs, the metal link will vaporize instantly and open the circuit.)

In a motor-starting situation, no heat is generated if the motor starts quickly, so the solder does not melt. If the motor binds or does not start promptly for some other reason, excess current flow generates enough heat to melt the solder. This delay feature permits the fuse to be sized according to the motor's *running* current, not the starting amps.

Time-delay fuses are sized according to ***full load amperage (FLA)*** of the motor. This information is located on the motor data plate. A time delay fuse is selected with a rating 25 percent greater than motor FLA (*oversized* by 25 percent). For example, a motor with an FLA of 8 amperes should use a 10 amp fuse.

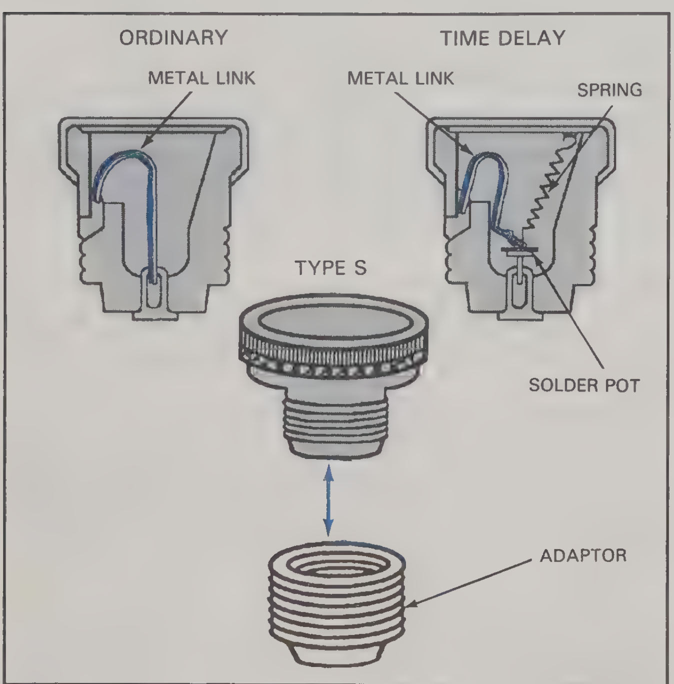


Fig. 20-18. Plug-type fuses are available as either ordinary or time-delay types. The Type S is a special time-delay fuse, with a different-sized threaded portion for each ampere rating. Adaptors assure that the proper-size Type S fuse is used.

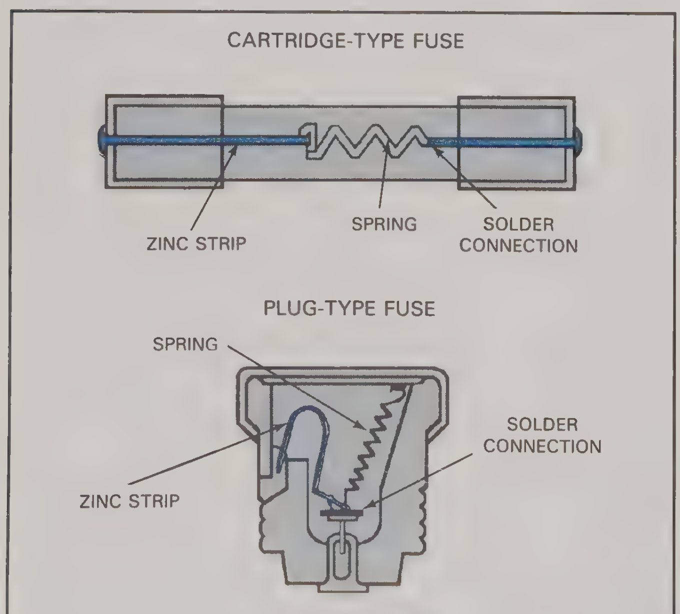


Fig. 20-19. Time-delay fuses allow overloads for short periods, such as the high current flow when a motor starts. Prolonged overloads will melt the solder connection, allowing the spring to open the circuit.

Type S fuse. This fuse has the time-delay feature, but is made with threaded sections in different sizes . The size varies according to the load amperage rating of the fuse. Type S fuses are used with an adaptor that screws into the socket on the fuse panel, and locks in place. The adaptor is almost impossible to remove and prevents installing the wrong size fuse in the circuit. Type S fuses are commonly used in mobile homes, because of the greater risk of fire in such installations.

Cartridge fuses

Cartridge fuses are available as ordinary fuses or dual-element time-delay type, Fig. 20-20. Round-end cartridge fuses are used up to 60 amperes. Knife-blade contacts are used for fuses over 60 amperes. It is important that the fuse ends make good contact in the fuse holder, Fig. 20-21. Poor connections, or a high air temperature around the fuse, will reduce its amperage rating and cause needless blows and shutdown.

Amperage and voltage ratings determine the physical size of the cartridge fuse. Fuse-holding devices, Fig. 20-22,

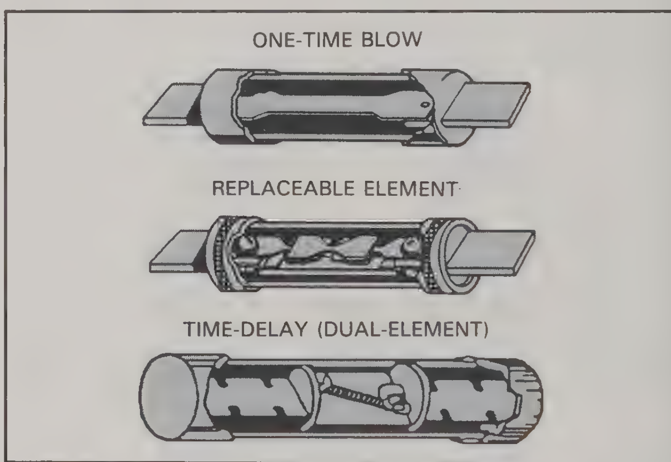


Fig. 20-20. Cartridge fuses are available in standard or time-delay (dual-element) types. In standard cartridges, either disposable (one-time-blow) fuses or those with replaceable elements can be used.

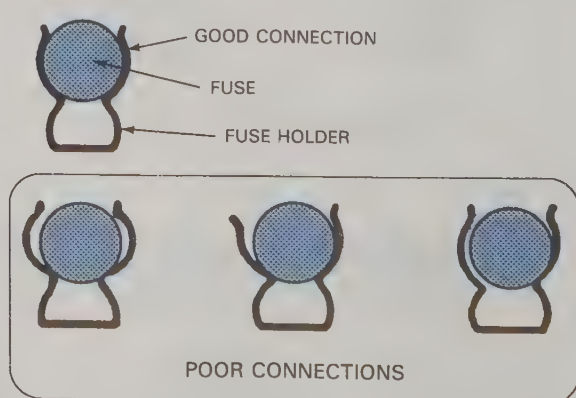


Fig. 20-21. A good mechanical fit between fuse and fuse holder is important. Poor connections will reduce the fuse's amperage rating.

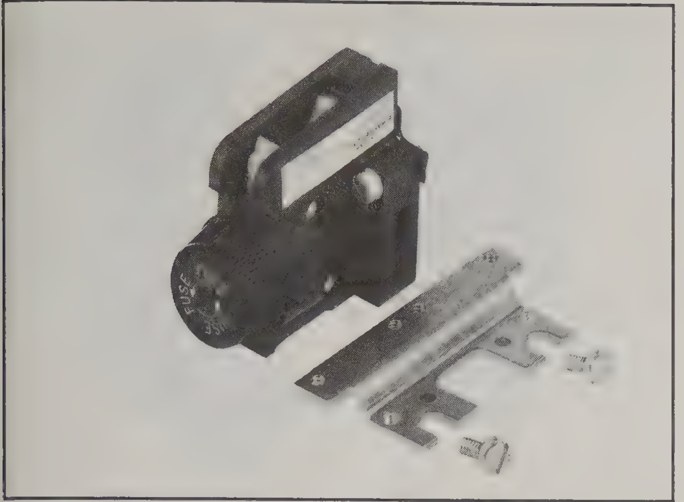


Fig. 20-22. Fuse-holding devices for cartridge fuses are made in various forms. This fuse holder kit has a screw-on cap that makes a good mechanical connection. (Cutler-Hammer)

are sized according to the same procedure, so that fuses and holders match. The fuse holders limit the maximum size fuse that can be used. This helps prevent oversizing fuses on circuits designed for a certain maximum amperage. For example, a cartridge fuse rated at 250 volts and having an ampere rating from 1/10 to 30 amperes will only fit into a receptacle designed for a maximum of 30 ampere service at 250 volts. See Fig. 20-23.

CIRCUIT BREAKERS

Circuit breakers are available as single-pole (one switch), double-pole (two switch), and three-pole (three switch) types. See Fig. 20-24. The ***single-pole breaker*** is used to disconnect the black (hot) wire on 120V, single-phase branch circuits. The ***double-pole breaker*** is used to disconnect both hot wires on 230V, single-phase branch circuits. A ***three-pole breaker*** is used to disconnect all three hot wires on a three-phase circuit.

Circuit breakers perform the same job as fuses, but can be reset after they "trip." When its load amperage rating is exceeded, the breaker trips (switches to the "off" position). All circuit breakers require a manual ***reset*** to the "on" position. Some breakers trip to a ***mid-position*** and must be turned to the off position before resetting to the on position. A tripped circuit breaker indicates an overcurrent problem in the circuit. Failure to correct the overcurrent problem will only result in another trip-out.

AMPERAGE RANGE	250 VOLT FUSE LENGTH (INCHES)	600 VOLT FUSE LENGTH (INCHES)
1/10 TO 30	2	5
35 TO 60	3	5 1/2
70 TO 100	5 7/8	7 7/8
110 TO 200	7 1/8	9 5/8
225 TO 400	8 5/8	11 5/8
450 TO 600	10 3/8	13 3/8

Fig. 20-23. This table shows lengths and ampere ranges for 250V and 600V cartridge fuses. Fuse holders are sized to limit the maximum amperage fuse that they can hold.

Circuit breakers serving a building or portion of a building are usually located in a load center or breaker panel, Fig. 20-25. The ***load center*** supplies electrical power to several branch circuits. The load center normally has a main circuit breaker located at the top of the panel to protect and disconnect power supply to the entire panel. Other circuit breakers are located below the main breaker and protect each of the branch circuits that obtain power from the panel. See Fig. 20-26.

The hot wires (black or red) for the branch circuit are connected to a circuit breaker. All white (neutral) wires are connected to a neutral busbar, which is in turn directly connected to a grounding electrode (earth ground). The

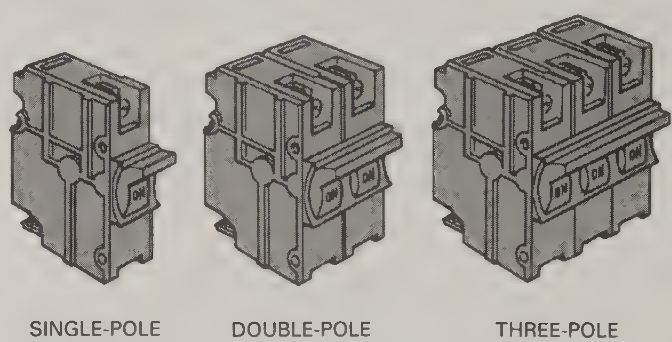


Fig. 20-24. Circuit breakers have one, two, or three switches, depending upon the application.

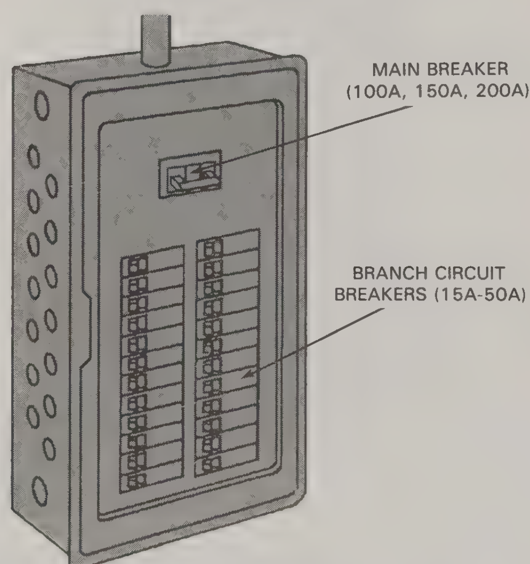


Fig. 20-25. A typical load center or breaker panel. The main circuit breaker disconnects the incoming electrical supply from the branch circuits. Branch circuit breakers protect individual circuits.

safety ground busbar is connected directly to another grounding electrode. In some residential systems, however, the safety ground wires are connected to the neutral busbar for direct access to a single grounding electrode. This is the *only* place where the neutral and safety ground may be connected together.

GROUND FAULT CIRCUIT INTERRUPTERS (GFCI)

The importance of a good *safety ground system* cannot be overemphasized. Many people have lost their lives due to lack of a safety ground, or as a result of poor grounding methods. A ground fault can occur due to defective, worn, or misused equipment, especially when that equipment is operated in damp or wet areas. Examples include portable power tools, hair dryers, electric shavers, and kitchen appliances. Such equipment *does* fail; when it fails, it presents a dangerous situation to the operator.

Fuses and circuit breakers do not protect people using such equipment. The ***ground fault circuit interrupter (GFCI)*** was designed to perform a dual role: it protects the circuit from overcurrent *and* protects people from potentially hazardous ground faults arising from the use of defective appliances or portable tools. See Fig. 20-27. The National Electrical Code requires the use of GFCIs in bathrooms, outdoors, swimming pool areas, attached garages, motel guest rooms, and all countertop receptacles within six feet of the kitchen sink. GFCIs are available as circuit breakers and receptacles. Extension cords with built-in GFCI protection are required for use with portable tools.

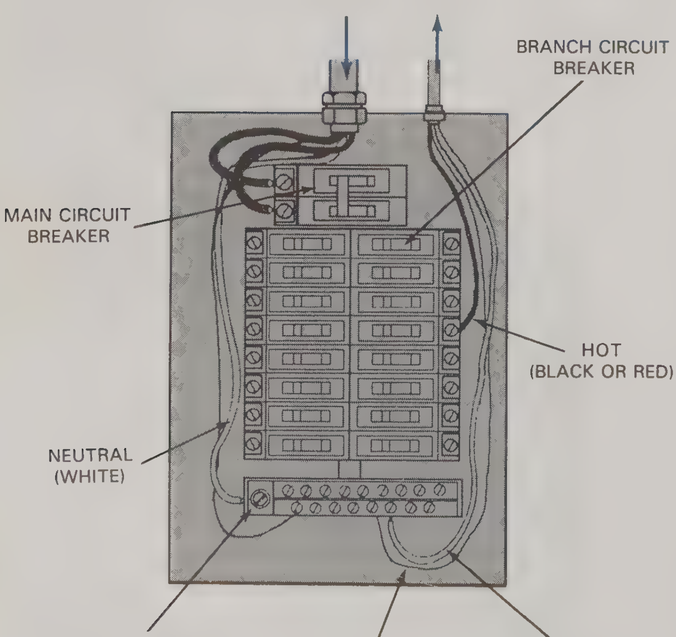


Fig. 20-26. The hot wire for each branch circuit is connected to the appropriate breaker, while the neutral wire is connected to a grounded neutral busbar. In some residential installations, the safety ground wire is also connected to the neutral busbar. For commercial installations, a separate safety ground busbar must be used.

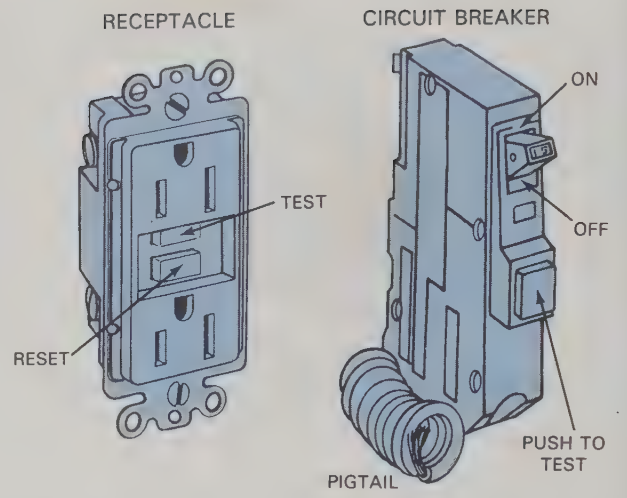


Fig. 20-27. Ground fault circuit interrupters protect people from potentially hazardous ground faults. They are available as receptacles or circuit breakers.

How the GFCI works

Normally, as shown in Fig. 20-28, current travels to an appliance along the black (hot) wire and returns along the white (neutral) wire. The amperage in each conductor is the same. No current flows through the safety ground.

When a ground fault occurs, however, the normal current flow pattern (through hot and neutral wires) changes: some current travels along the safety ground wire (or through a person's body) to ground. This flow creates an *imbalance* of amperage between the hot and neutral wires.

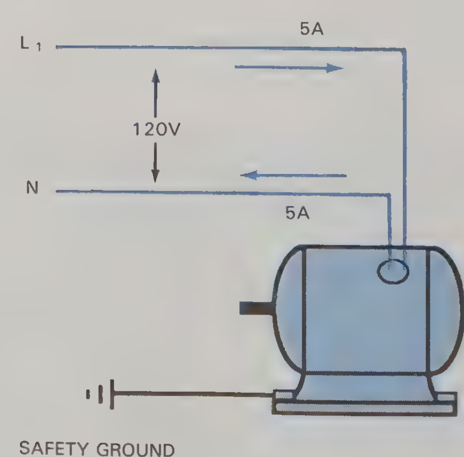


Fig. 20-28. Normal current flow in a motor circuit. Amperage in the hot wire (L_1) and the neutral wire (N) is equal. No current flows through the safety ground wire.

The GFCI monitors current flow in both the hot wire and the neutral, and is very sensitive to any imbalance. Since an imbalance can only occur during a dangerous fault to ground, the GFCI will open the circuit whenever the imbalance reaches about 4-6 milliamperes (mA). See Fig. 20-29.

As noted earlier, the GFCI serves a dual purpose: people *and* circuit protection. Thus, if the normal load amperage rating (15A, 20A, or 30A) is exceeded, it will open the circuit. In this manner, it operates much like an ordinary circuit breaker.

ELECTRICAL CONNECTIONS

Wires are the ***conductors*** or pathways that carry electrical energy from place to place. They connect to each other and terminate at various electrical devices, and are covered with ***insulation*** to prevent energy loss. Where connections must be made, about 1 in. of insulation is removed from the wire end. This normally allows enough bare wire to make proper metal-to-metal connections.

Properly made connections require a clean, tight contact between the conductor and device terminals. The National Electrical Code does not permit splicing or connecting wires except inside a proper housing. Connections to an electrical device also must be made inside an approved housing or box. Connections between copper and aluminum can be made *only* with use of an approved connector.

Poor connections are a constant source of electrical problems. A loose connection permits arcing and becomes a built-in resistance. Such poor connections cause voltage drop, energy loss, and overheating. The importance of good electrical connections cannot be overemphasized.

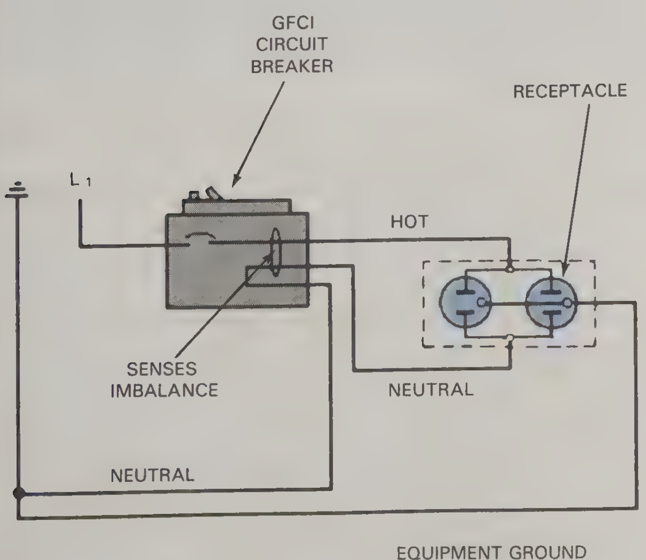


Fig. 20-29. A GFCI senses an amperage imbalance between hot and neutral wires as a result of a ground fault. It quickly opens the circuit to prevent injury to a person who might become part of the circuit.

MAKING TERMINAL CONNECTIONS

When a solid conductor is connected to a screw-type terminal, the wire end must be formed in a loop. Longnose pliers are used to form a circular loop to the right, as shown in Fig. 20-30.

To achieve good contact, the loop should encircle the screw shaft in a *clockwise* direction for about 3/4th distance around it. The screw is inserted through the loop and turned clockwise to tighten it. This causes the loop to be pulled inward for a tight connection. If the loop in the wire was made to the left (counterclockwise), tightening of the screw will cause it to open outward. This results in a poor, and possibly unsafe, connection. See Fig. 20-31.

Terminal connectors

Quick-connect ***terminal connectors*** that crimp onto the wire ends are very popular and easy to use. Types and sizes are available to fit most applications. See Fig. 20-32. When installed properly, they avoid most problems arising from loose connections.

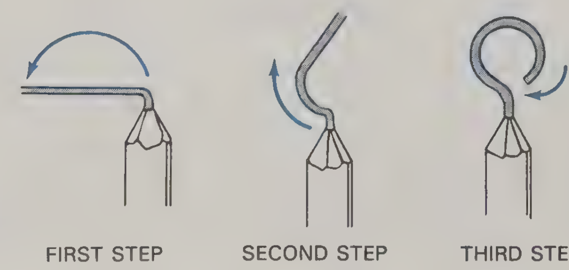


Fig. 20-30. A proper loop for wire connection to a screw terminal is made using longnose pliers. The loop must be made in a clockwise (right-hand) direction.

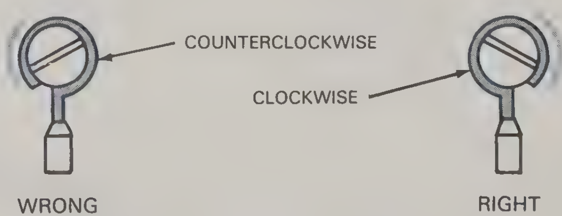


Fig. 20-31. The loop must encircle the screw in a clockwise direction, so that it will be pulled inward as the screw is tightened. A counterclockwise loop tends to open as the screw is tightened.

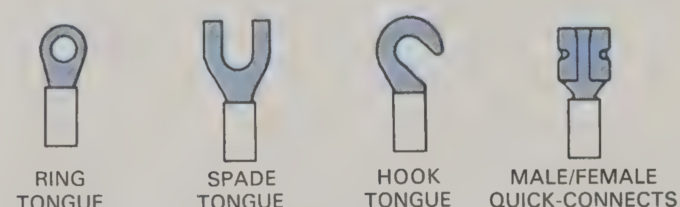


Fig. 20-32. Different types of terminal connectors are available for different applications. They can almost eliminate loose connection problems.

To install a connector on a wire, about 1/2 in. of insulation is removed from the wire end. The bare end is then inserted into the connector, and a special tool is used to *crimp* (squeeze) the connector tightly onto the wire end. As shown in Fig. 20-33, two crimps are usually used to achieve a secure bond between the wire and the connector. After crimping, always check to see if connector will pull off the wire. A special plastic insulation covers the crimped connection.

Solderless screw-on connectors

Solderless screw-on connectors are commonly called *wire nuts.* They eliminate the need for soldering connections and are NEC-approved. Wire nuts are available in several sizes and made of plastic or Bakelite® insulating material. To install a wire nut, remove about 1/2 inch of insulation from the wire ends. Twist the bare ends together and screw the nut onto twisted wires. See Fig. 20-34. Be certain the nut is tight and will not fall off. Wire nuts *can* become loose and allow wires to separate inside them. To prevent loosening, use electrical tape to secure wire nut on wire ends.

SUMMARY

Troubleshooting and repair of motor control and circuit protection devices are everyday activities for the HVAC technician. This chapter described the power transmission system and the various types of transformers used to reduce voltage to usable levels in residential and commercial installations. Also described were the different types of circuit protection devices and their operation. Also covered was the importance of making good terminal connections, and the available types of connectors. Skills acquired in these areas will improve your ability to diagnose and correct system problems.

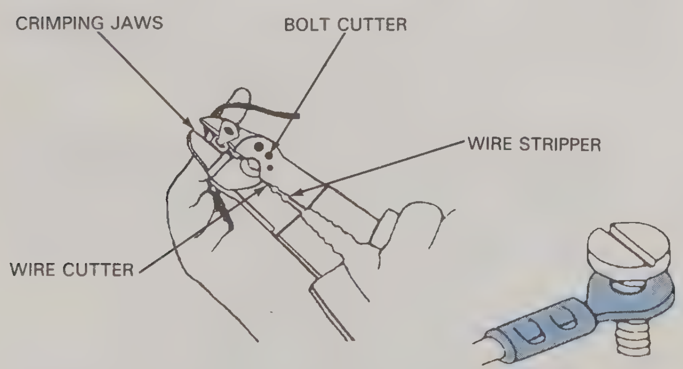


Fig. 20-33. A special multiple-use tool is used to crimp the connector to the wire end. As shown at right, two crimps are usually made in the connector to assure a good bond to the wire.

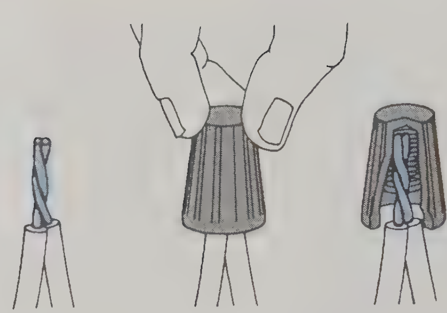


Fig. 20-34. A wire nut is installed by twisting the bare wire ends together, then screwing the nut onto the twisted wires. For a sound mechanical and electrical connection, the wire nut must be tight.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. A step-up transformer __________ voltage.
2. Most residential units are provided with two hot wires and a neutral wire. What is the supplied voltage? How many phases are supplied?
3. True or false? Single-phase power is obtained from a three-phase system.
4. An important advantage of alternating current is that it can be __________ at one voltage, transmitted at __________ voltage, and then reduced to a lower voltage at the __________.
5. What is the basic principle that is involved in the operation of a transformer?
6. Ampacity is the amount of __________ a wire can safely carry.
7. Name the two devices commonly used for protection against overcurrent.
8. True or false? A dual-element plug fuse should be used in ciruits serving electric motors.
9. What two ratings determine the physical size of a cartridge fuse?.
10. A GFCI protects people against a __________ fault.

Chapter 21

INDUCTION MOTORS

After studying this chapter, you will be able to:
- *Identify five types of single-phase induction motors.*
- *Describe the methods of operation of induction motors and typical applications.*
- *Demonstrate how to make proper motor connections.*
- *Use an ohmmeter to identify hermetic motor-compressor terminals.*
- *Troubleshoot induction motor problems.*
- *Select and connect start components.*
- *Identify examples of multi-speed and dual-voltage motors.*
- *Select and install proper fan replacements.*

NEW WORDS

arcing
axial
bearing
bimetallic
bleed resistor
bushing
capacitor
capacitor-start, capacitor-run (CSCR) motor
capacitor-start, induction-run (CSIR) motor
centrifugal
centrifugal switch
common
cubic feet per minute (cfm)
cycling on the overload
dielectric
dual-voltage motors
electrodes
fractional horsepower
full load amps (FLA)
induced magnetism
integral horsepower
jumper bars
laminated
lead end
locked rotor amps (LRA)
microfarads
motor overload
multi-speed motor
open capacitor
open winding
permanent split capacitor (PSC) motor
plates
poles
revolutions per minute (rpm)
rotation
rotor
run capacitor
run winding
series-parallel
shaded pole motor
shading coil
shaft end
short-cycle
shorted capacitor
shorted to ground
slip
split-phase motor
squirrel cage rotor
start capacitor
start winding
stator
synchronous speed
taps
torque
VAC
velocity
zerk fitting

INDUCTION-TYPE MOTORS

Electric motors of the induction type are common in refrigeration, heating, and air conditioning applications, where they are used to drive compressors, fans, pumps, and other devices. Since a motor malfunction causes severe system problems, the technician must possess a good working knowledge of motors and their operation to properly troubleshoot a system and perform necessary repairs. Sometimes, the motor malfunction is a warning of other system problems that must be identified and solved.

There are six basic types of induction motors: five single-phase and one three-phase. Although methods of operation are similar, each type serves a different purpose. It is sometimes necessary to convert from one type of motor to another to achieve better operating characteristics.

PRINCIPLES OF INDUCTION MOTOR OPERATION

The induction motor uses ***induced magnetism*** (magnetism that is caused by an electric current) to convert electrical energy to mechanical energy. As shown in Fig. 21-1, a cylinder (***rotor***) is rotated inside a magnetic field produced by stationary electromagnets (***stator***).

An electromagnet has two distinct advantages:

1. Its core is magnetized only when current flows through the coil. When no current flows, there is no magnetic field.
2. The polarity of an electromagnet can be changed by reversing the direction of current flowing through its coil. Ordinary 60-cycle alternating current automatically reverses the polarity of the stator poles 120 times per second. See Fig. 21-2.

Two or more stationary electromagnets (called ***poles***) are positioned at opposite sides of a circle inside the motor. These stationary poles have *opposite* magnetic polarity. When the alternating current flow automatically changes from positive to negative, the polarity of the electromagnets will reverse as well (North to South, or South to North). The polarity of the electromagnets changes constantly as the current alternates. By placing the stationary electromagnets in a circle, a *rotating* magnetic field is produced.

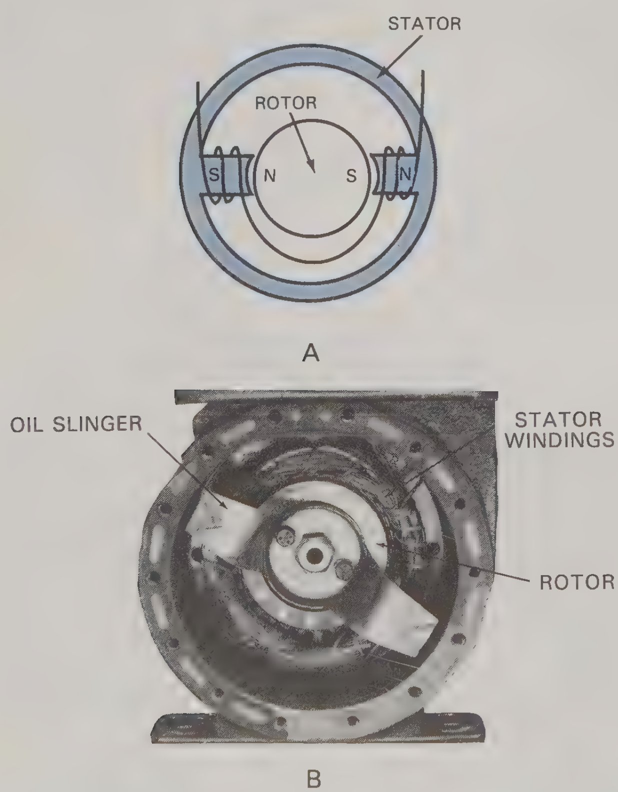


Fig. 21-1. Main parts of an induction motor. A–A simplified end view of an induction motor, showing the magnetic poles of the stator and rotor. B–With end bell of a motor-compressor removed, the rotor and the stator windings can be seen easily.

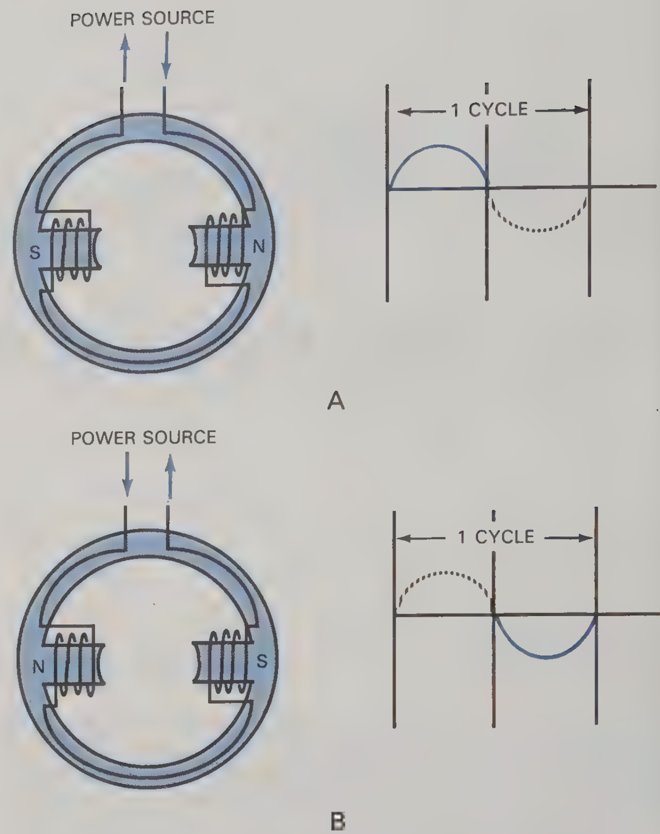


Fig. 21-2. Alternating current automatically reverses the polarity of the stator's magnetic poles during each cycle.

A soft iron core (the rotor) is placed in the center of the rotating magnetic field, and magnetism is induced in it that is opposite the polarity of the stator. Since opposite magnetic poles attract, the rotor is locked in position. If the rotor is given a spin, it will continue to rotate due to attraction and repulsion of the alternating polarity in the stator poles.

The rotor continues to spin because its South pole is attracted by the stator's North pole and repelled by the stator's South pole. This push-pull action is continuous, making the rotor spin as the stator poles change polarity. The rotor tries to catch up with the stator's rotating magnetic field. See Fig. 21-3.

Stator

Motors have stationary coils of copper wire (main windings) that are carefully wrapped around ***laminated*** (layered) cores of soft iron. As you saw in Fig. 21-1, these coils and laminated cores are permanently mounted around the inside of the motor shell. This arrangement of coils and cores is called the *stator*.

The stator coils are wrapped to produce a North pole and a South pole. The poles are located directly opposite each other, or 180° around the circle, Fig. 21-4. Opposing polarity is produced by wrapping the first pole in one direction, then wrapping the other pole in the opposite direction. Thus, the two poles are located 180° apart, wired in series, and wrapped in opposite

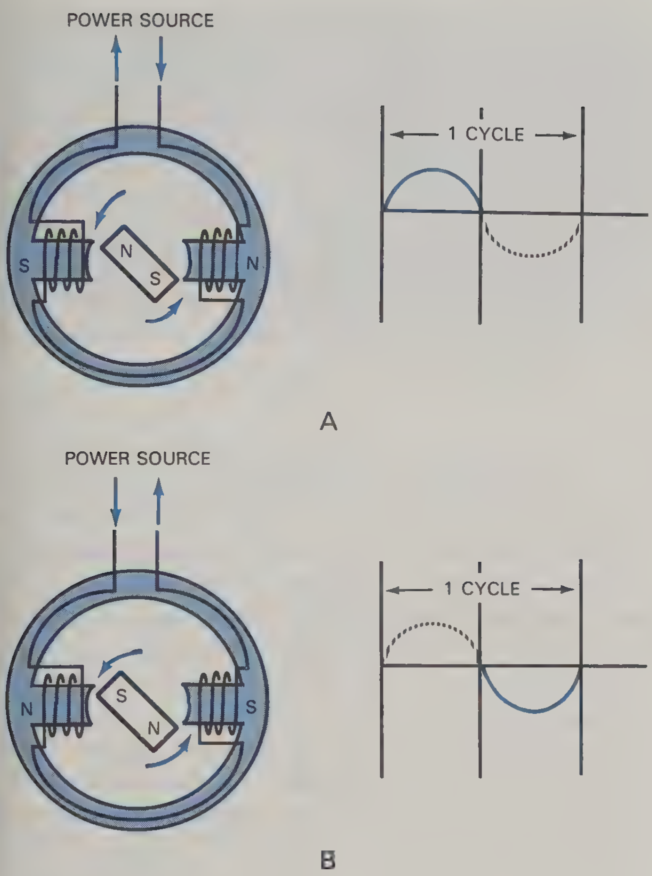


Fig. 21-3. As the stator's magnetic field rotates because of changing electric current flow, the rotor keeps turning as it tries to "catch up" with the opposing magnetic polarity.

directions. This winding of the stator coils is normally called the ***run winding.***

The size (diameter) of copper wire used and the number of wraps in the coil determine the amount of resistance in the coil. The coil resistance limits the amount of current flowing through the wire. The amount of current, in turn, determines the strength of the magnetic field in the core.

Rotor

The ***squirrel cage rotor,*** Fig. 21-5, is the most common rotor type used in induction motors. Its body consists of a laminated soft iron cylinder enclosing and attached to the motor shaft. Instead of wires, copper bars are inserted into slots formed in the surface of the core. The ends of these copper bars are joined together, forming a series of closed loops arranged in a sort of squirrel cage; hence its name.

The magnetic field established by the stator cuts across the closed loops in the rotor, inducing large currents in them. As a result of these induced currents, the rotor becomes a magnet that is rotated by the rotating magnetic field of the stator.

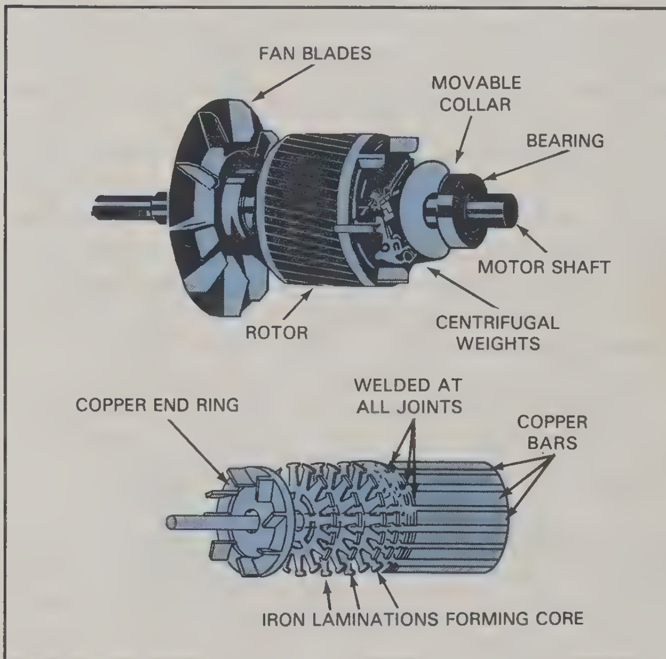


Fig. 21-5. A squirrel cage rotor consists of a laminated iron core with copper bars inserted in it. The core surrounds the motor shaft. Construction is shown at bottom.

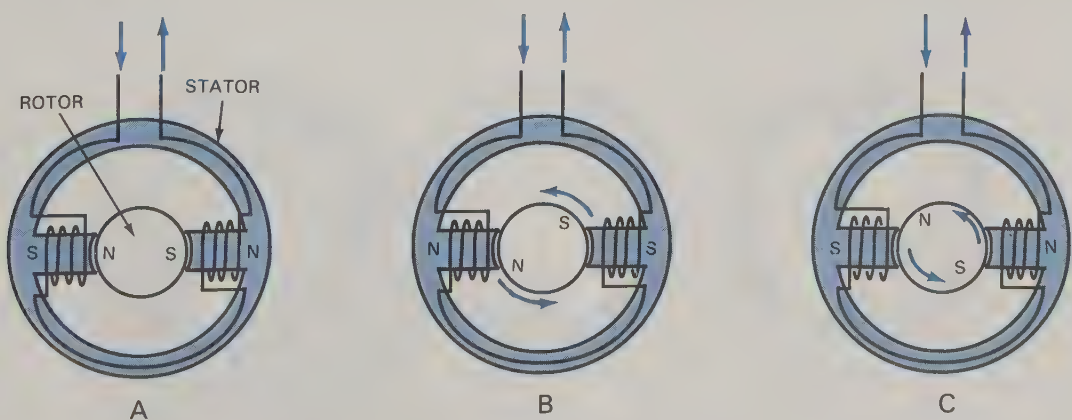


Fig. 21-4. Rotation of an induction motor's rotor is a result of the stator's changing magnetic field. A–Current flow through the stator induces opposite polarity in the rotor. B– Alternating current flow causes the stator polarity to reverse. The rotor rotates as its poles try to remain opposite those of the stator. C–The rotation continues as stator polarity once again changes.

Motor speed

Motor speed is determined by dividing the number of stator poles into the number of times the current changes direction (alternates) per *minute*. Because two alternations occur per cycle, 60 cycle current changes direction 120 times per *second*. Motors are rated in ***revolutions per minute (rpm)***, so alternations must be figured on a "per minute" basis. Therefore, the current alternates 7200 times per minute ($120 \times 60 = 7200$). See Fig. 21-6.

For every alternation of current flow, the rotor travels from one stator pole to the next. Thus, with a two pole motor, the rotor makes one complete revolution for every two alternations (one cycle). The speed of a two-pole motor is 3600 rpm ($7200 \div 2$). The rpm of a four-pole motor is 1800 rpm ($7200 \div 4$); it requires four frequency changes (two cycles) for the rotor to make one complete revolution. A six-pole motor rotates at 1200 rpm ($7200 \div 6$). This motor requires six frequency changes (three cycles) for the rotor to make one complete revolution.

In theory, the rotor will adjust itself to the rotating magnetic field in the stator poles. This is called ***synchronous speed.*** Synchronous speed is nearly achieved when there is no load on the motor. The *actual* running speed of a motor is slightly less than synchronous speed, since the rotor tends to lag behind the rotating field as the motor is loaded. The greater the load on the motor, the more the rotor lags behind the rotating field.

With a motor running at full load, the rotor turns at about 4 to 5 percent below synchronous speed. This difference in motor speed is called ***slip.*** See Fig. 21-7.

Horsepower

Motors are often rated by the amount of ***torque*** (turning power) they can produce. This turning power is rated in horsepower. The traditional measure of horsepower, as used in England, is the amount of power required to lift 550 pounds one foot in one second.

In the United States, horsepower is calculated using the power needed by the motor to produce torque. This power is rated in watts, with 746 watts equal to one horsepower. Thus, a five hp motor will use 3730 watts ($5 \times 746 = 3730$). When the wattage and voltage are known, Ohm's Law makes it possible to determine the amount of amperage draw under full load conditions.

Motors rated at less than one horsepower are called ***fractional horsepower*** motors. Motors of one or more hp are called ***integral horsepower*** motors.

MOTOR SPEEDS		
NUMBER OF POLES	SYNCHRONOUS SPEED	ACTUAL SPEED
TWO-POLE MOTOR	7200 ÷ 2 = 3600 RPM	3450 RPM
FOUR-POLE MOTOR	7200 ÷ 4 = 1800 RPM	1725 RPM
SIX-POLE MOTOR	7200 ÷ 6 = 1200 RPM	1150 RPM

Fig. 21-7. This table compares the synchronous speed of various motors with the actual speed under load.

Efficiency

Electric motors are not 100 percent efficient. Like any machine, some losses occur in a motor when it operates. The efficiency of a fractional hp motor may be less than 50 percent, but an integral motor may be over 90 percent.

Power loss in a motor is converted to heat energy. Motor cooling must be provided to dissipate (get rid of) this heat. Open-type motors are cooled by fans that draw air through openings in the motor frame and blow it over the windings. Sometimes, fan blades are attached to the rotor shaft inside the motor to blow air through the windings. See Fig. 21-8. For effective cooling, openings in the motor ends must be kept free of dirt and lint.

Motors that are located inside hermetic and semi-hermetic compressors are often cooled by returning cool suction gas. However, additional cooling is sometimes provided by an externally mounted fan, by liquid injection, or by cooling the crankcase oil.

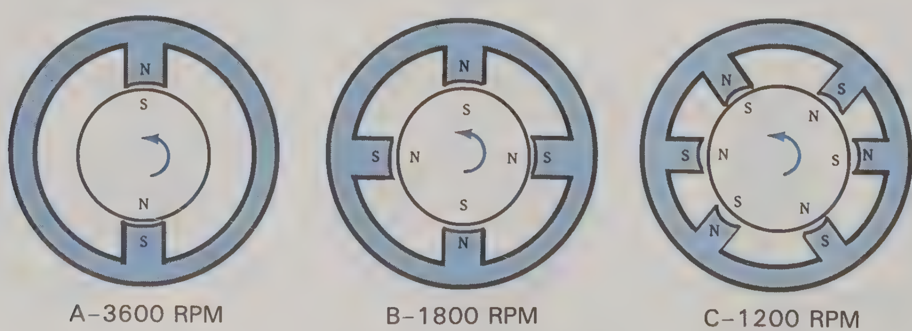


Fig. 21-6. Since 60-cycle current alternates 7200 times per minute, the number of stator poles determines motor speed. A–With two poles, the rotor turns 1/2 revolution for each current alternation, or 3600 rpm. B–With four poles, the rotor turns 1/4 revolution per alternation, or 1800 rpm. C–With six poles, motor speed drops to 1200 rpm as the rotor turns only 1/6 revolution per alternation.

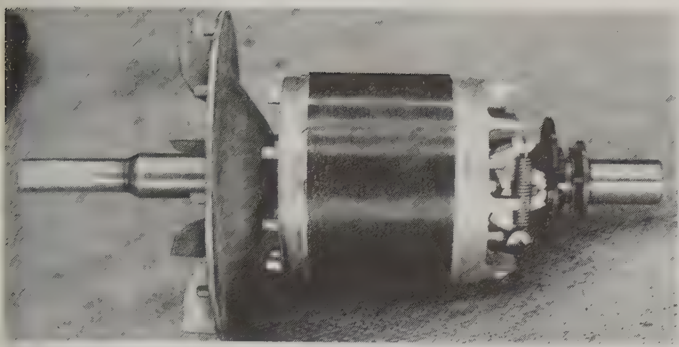


Fig. 21-8. To provide cooling in an open-type motor, fan blades may be attached to the same shaft as the rotor.

SINGLE-PHASE MOTORS

Single-phase motors will not start with just the run (main) winding. The polarity of the stator and rotor are "in step," so the poles of the rotor always face unlike poles of the stator. This attraction of unlike poles results in a locked rotor. If you physically give the rotor a spin, however, it will continue to turn in its effort to catch up with the stator's rotating magnetic field. When the applied current is turned off, the magnetic fields disappear and the motor stops.

START WINDING

To accomplish automatic starting, another field (stator) winding is required. This additional winding is called the ***start winding.*** It establishes another magnetic field in the stator that is "out of step" with the main winding. As shown in Fig. 21-9, the start winding is placed at a 90° angle from the main winding.

At start-up (when the main switch closes), current flows through both start and run windings. The start winding has much smaller diameter wire and has more turns in the coil, so it has high resistance. Magnetism builds up faster in the run winding, because it has less resistance. These two separate magnetic fields, one behind the other, create a turning force on the rotor.

Direction of rotation

Rotation (clockwise or counterclockwise) is determined by the direction of current flowing through the start winding. ***Rotation*** of the shaft is compared to the hands on a clock. If the shaft is turning to the right, rotation is clockwise (CW). If the shaft is turning to the left, rotation is counterclockwise (CCW). To reverse rotation, simply reverse the two connections to the start winding. This causes current flow in the opposite direction through the start winding and causes opposite polarity and rotation.

On open-type motors, the electrical connections are located at one end of the motor (called the ***lead end***); the rotor shaft exits the opposite end of the motor (the ***shaft end***). See Fig. 21-10. For most types of motors, the direction of rotation (CW or CCW) is identified as viewed from the shaft end toward the lead end. Motors made by General Electric are an exception: direction of rotation is determined by viewing from the lead end toward the shaft end. Direction of rotation should always include which end of the motor is being viewed.

Disconnecting the start winding

The only purpose of the start winding is to get the rotor moving. Because of its high resistance, the start winding will *burn out* if it is not disconnected from the circuit

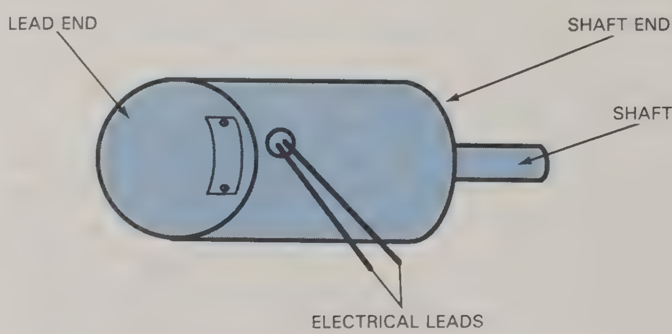


Fig. 21-10. When describing rotation of a motor shaft, the end of the motor from which the rotation is viewed must be noted.

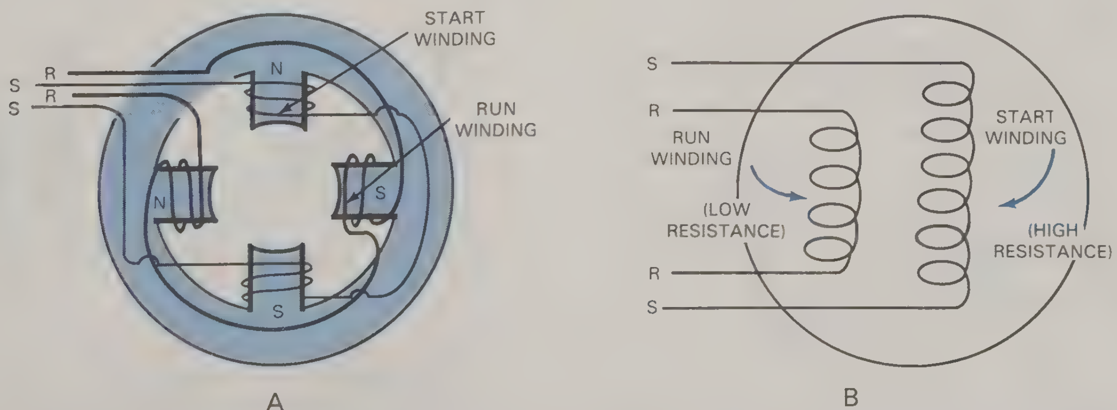


Fig. 21-9. The start winding, in this two-pole motor, is spaced 90 ° apart from the run winding. This produces magnetic fields that are ''out of step,'' to keep the rotor turning.

once the motor reaches about 75 percent of normal speed. This happens very quickly, usually in less than one second.

One of three methods is used to disconnect the start winding from the circuit, depending upon the type of motor. Open-type motors use a *centrifugal switch,* small hermetics use an *amperage relay,* and larger hermetics and semi-hermetics use a *potential relay*. Amperage and potential relays are fully explained in Chapter 22.

The centrifugal switch used to disconnect the start winding of an open-type motor is normally located inside the motor frame. The switching device (amperage or potential relay) that is used by hermetic and semi-hermetic compressors must be located outside the metal housing. *Exterior* relays must be used because of the ***arcing*** (sparks) that occurs when switching contacts open or close. Arcing would create damaging acids inside the hermetic unit by causing a breakdown of refrigerant and compressor oil.

The run winding and start winding are two separate loads and must be connected in parallel. See Fig. 21-11. A switch is connected in series with the start winding and is used to disconnect the start winding after start-up. Another switch is used to control power supply to the motor, and is connected in series with both windings. The main switch controlling the motor's power supply can be installed at any remote location.

Locked rotor amps (LRA)

At start-up, there is little or no counter-emf generated by the motor. Amperage flow is determined strictly by the resistance of the motor windings. Starting current flow is typically about six times higher than normal running amperage. This high current flow is called ***locked rotor amps (LRA).*** As the motor picks up speed, counter-emf is generated and rapidly increases the motor's resistance to current flow. As noted earlier, the start winding is disconnected at about 75 percent of normal speed. Amperage flow is then greatly reduced; the motor operates on the run winding alone. Amperage flow is now determined by the resistance of the run winding combined with the counter-emf generated by the motor.

Full load amps (FLA)

Immediately after the start winding is disconnected, the resistance of the run winding is increased by the counter-emf generated by the motor. This operating ("running") amperage is called ***full load amps (FLA).*** Induction motors usually operate at less than FLA, because the motor is only rarely working at fully loaded conditions. An overload occurs when the amperage flow exceeds the FLA rating on the motor data plate. Except for the temporary high start-up amperage, *any* amperage that exceeds the FLA rating will be converted to heat energy.

OVERLOAD PROTECTORS

The induction motor is designed to convert electrical energy to mechanical energy. Anything that prevents the rotor from turning in a normal manner will result in excess amperage flow, which the motor converts to heat energy that will destroy (burn out) the motor windings. The two most common causes of excess amperage flow (and thus excessive heat) motor problems are:

- A locked rotor (rotor physically unable to turn)
- An overload (rotor turning too slowly)

The ***motor overload*** is a device that protects the motor windings from damage caused by overheating due to overloaded conditions or poor ventilation.

The most common form of motor protector uses a snap-acting ***bimetallic*** disc to make and break a set of contacts. See Fig. 21-12. The snap action is obtained by fusing together two thin circular discs of different metals, usually steel on top and copper on the bottom. The bimetallic disc is anchored at the center. Since copper expands

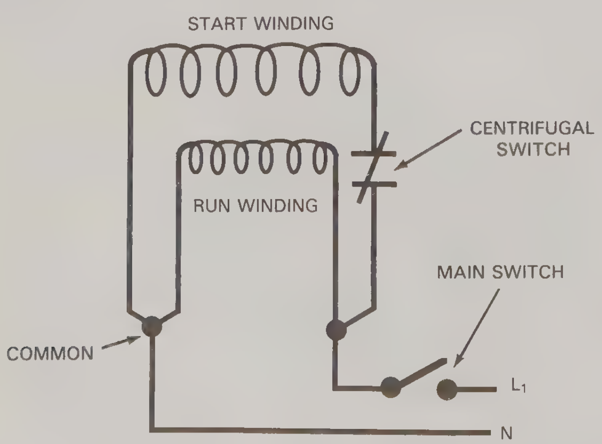


Fig. 21-11. The run and start windings, which are separate loads, are connected in parallel. The switch used to disconnect the start winding is in series with that winding.

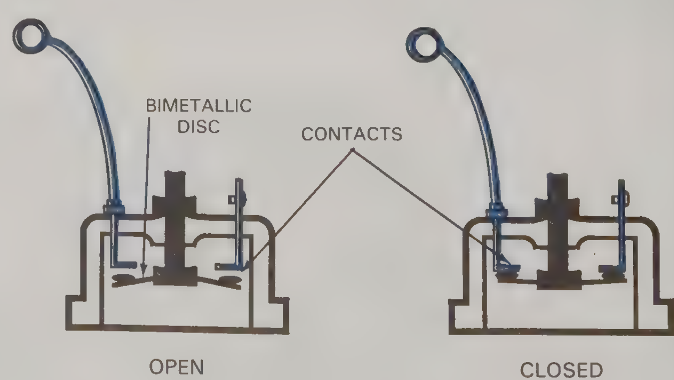


Fig. 21-12. A bimetallic disc of steel and copper is used in many overloads. When sufficiently heated by an overload, the differing expansion rates of the metals will cause the disc to curl in one direction. This will open the contacts and break the motor circuit. When the motor cools sufficiently, the disc will return to its normal shape, closing the contacts again.

faster than steel, a rise in temperature will cause the disc to expand. The outer edge will curl (bow) upward.

The movement will open a set of stationary contacts. Excessive heat from any source will affect this overload and cause it to open the circuit supplying power to the motor. When the bimetallic disc cools, it will snap back to its original (closed) position.

Cycling on the overload

If the overload condition is not corrected, the bimetallic disc will trip again and again. This is called ***cycling on the overload.*** After each trip, it requires more and more time for the bimetallic disc to cool. Eventually, it could require up to one hour for the bimetallic disc to cool and reset. Cycling on the overload is usually easy to hear, as the motor makes a noise that can be described as "hmmm...click." The humming noise is made by the motor trying to start, and the sharp "click" is heard when the bimetallic disc snaps open.

Cycling on the overload indicates a condition that *must* be corrected. The overload protector is sensitive to three sources of heat:

- Excess amperage flow (usually an electrical problem related to the start winding and start components).
- Excess motor heat (usually resulting from dry or badly worn bearings).
- Excess compressor heat (low on oil or compressor cooling is not working).

Tripping of the overload protector is a warning that the motor is in danger of a burnout. It is important to locate and repair the cause of an overload.

Two-wire overload connections

The terminals on the overload protector are numbered 1, 2, and 3. The contacts are located between numbers 1 and 2, while a small pure resistance heater wire is located between numbers 2 and 3. This resistance heater makes the overload react more quickly to overheating. See Fig. 21-13. Connections to the overload are limited to terminals 1 and 3. This simplifies electrical connections and prevents bypassing the heater. The heater is internally connected in series with the contacts.

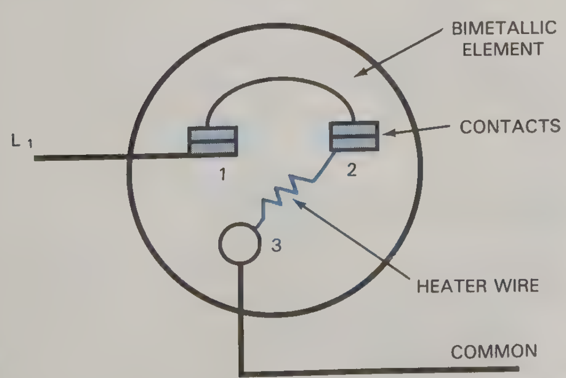


Fig. 21-13. A resistance heater wire, connected in series with the bimetallic element, makes the overload react more quickly.

One side of the supply voltage is connected to terminal 1, so that the current must flow through the contacts *and* the small heater to reach terminal 3. A wire from terminal 3 is connected to the *common* on the motor windings. ***Common*** is a term used to describe the wire that is used to connect one end of the run winding and one end of the start winding. Current flowing through this wire will supply power to both windings, so it is "common" to both windings. See Fig. 21-14.

Three-wire overload connections

On open-type motors, a three-wire connection is often used for the overload protector. Power supply is connected to terminal 1, the run winding to terminal 2, and the start winding to terminal 3. See Fig. 21-15.

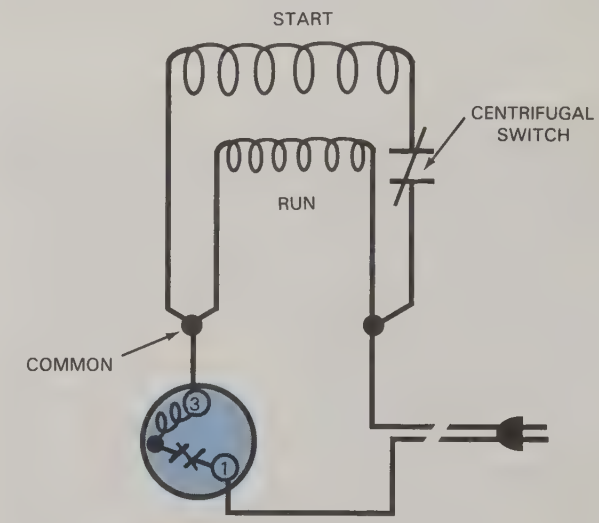


Fig. 21-14. The overload is in series with the common connection to the run and start windings. It is thus able to protect against excess current flow through either winding.

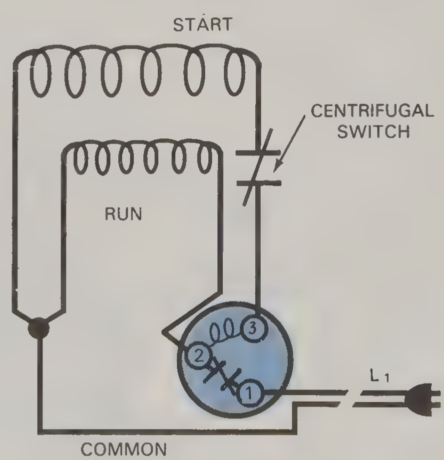


Fig. 21-15. Three wire connections to the overload use all three terminals. The heater is connected in series with the start winding, so that the overload will react more rapidly to any problem with the winding.

The heater inside the overload is connected in series with the start winding. This connection makes the overload respond quickly to any fault in the start winding, which is the source of many motor problems. During normal operation, the *run* winding is protected by the bimetallic disc only. However, if the bimetallic disc opens the contacts between 1 and 2, the power supply to both windings will be interrupted.

Internal overload protection

Many larger hermetics and semi-hermetics have an overload that is actually buried inside the motor windings. This overload can sense the current draw of the motor as well as the temperature of the windings much better than external overloads. It is installed at the factory and is not accessible to the technician. See Fig. 21-16.

The internal overload is usually a bimetallic element that will open the circuit and stop the motor if the winding temperature reaches 200-250° F (93-121°C). It will close again when the winding temperature drops to about 150-175° F (66-79°C). Depending on ambient temperature conditions, it may take one or two hours before the protector cools enough to close the contacts. Cooling the unit with forced air or ice will speed up the process. Unless an ohmmeter test confirms an open motor winding, do not condemn a motor until sufficient time has passed to allow the overload to reset.

TYPES OF INDUCTION MOTORS

Five types of single-phase induction motors, plus the three-phase induction motor, are in general use for heating, cooling, and refrigeration applications. The motor types are listed below according to the amount of turning power they produce, from least to greatest:

- Shaded pole.
- Split-phase.
- Permanent split capacitor (PSC).
- Capacitor-start, induction-run (CSIR).
- Capacitor-start, capacitor-run (CSCR).
- Three-phase.

The type of motor to be used for a particular application is determined by the location and type of load to be placed upon it. Each type of motor is available in various horsepower ratings.

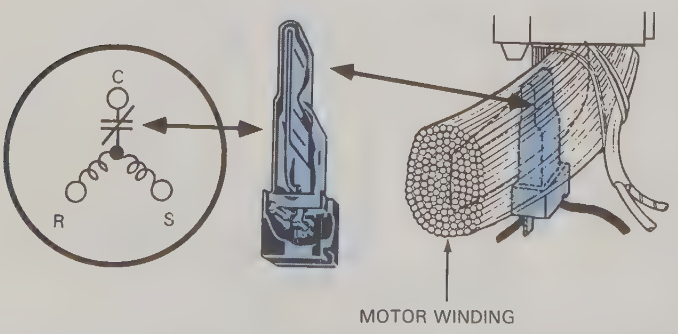


Fig. 21-16. An internal overload is actually built into the motor windings themselves. It is not accessible to the technician.

SHADED POLE MOTOR

The ***shaded pole motor*** is a specially designed, low-cost motor. It is often used to operate small fans, such as the evaporator and condenser fans on domestic and light commercial refrigeration units. See Fig. 21-17. This motor has a very low starting torque, but can carry a load once it is up to speed. This feature makes it an ideal motor for operating small fans. At start-up, the only load on the motor is the weight of the aluminum fan blades. Full load is not picked up until the blades are turning at operating speed and moving volumes of air.

Construction of the shaded pole motor is different from the construction of other induction motors. As shown in Fig. 21-18, a slit is cut at the edge of each stator pole, producing a small prong. A single closed loop of wire, called a ***shading coil,*** is placed over the prong. The shaded pole produces a tiny magnetic field that is "out of step" with the main poles. It is *not* a start winding in the normal sense, because the shading coil is not connected separately to a power source.

The shaded pole provides just enough magnetism to start the rotor turning, then the rotating magnetic field in the main poles provide the necessary torque to bring the rotor up to full speed. The shaded pole is constantly energized when the motor is running, but this small amount of energy is only a factor at start-up.

Shaded pole motors are available from 1/100 hp to 1/6 hp. If a shaded pole motor malfunctions, it is usually cheaper to replace it than to repair it. Electrical connections are easy, because only two wires are involved–power supply is connected to each end of the motor winding.

Reversing rotation

Direction of rotation of the shaded pole motor is determined at the factory by locating the shaded poles on one side or the other of the main poles. A left-side location gives CCW rotation and a right-side location results in CW rotation. The location of these poles cannot be changed in the field. Reverse rotation can be achieved only if the rotor can be physically removed and reversed (reinstalled so the shaft exits the opposite end of the motor). This reversing of the rotor is not always possible.

SPLIT-PHASE MOTOR

The name of the ***split-phase motor*** explains its principle of operation: a start winding is installed in the stator to produce a magnetic field that is "out of phase" with the main winding. The start winding is rather delicate, because of higher resistance created by the use of smaller wire and more wraps per coil. The start winding assists the motor in getting started, but begins to inter-

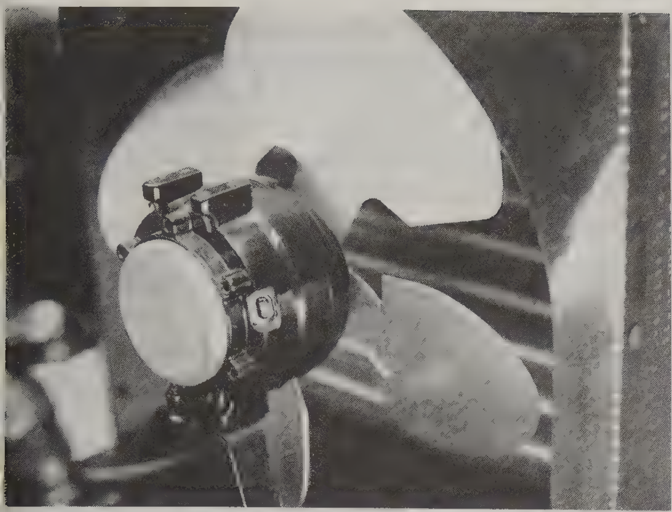


Fig. 21-17. A shaded-pole motor used to operate a condenser fan on an air conditioning unit.

fere with the magnetism of the run winding at about 75 percent of normal speed. This conflict of magnetic fields will cause the motor to burn out, if the start winding is not promptly taken out of the circuit.

Application

The split-phase motor has fairly low starting torque, but good running torque. Open-type split-phase motors are popular for fans or blower motors where the load is too large for a shaded pole motor. This type of motor is very popular in hermetics for use on systems with capillary tube refrigerant control, such as domestic refrigerators and window air conditioners. During the off cycle, the capillary tube permits some high-side pressure to bleed over to the low-pressure side of the system. This bleedover helps reduce head pressure and makes it possible to use a less- costly motor that has low starting torque. To allow time for head pressure to drop, a capillary tube system should not be restarted for about two to five minutes after it is stopped.

Open-type split-phase motor

On open-type motors, a terminal board used for making electrical connections to the motor windings is located just inside the end bell (lead end). See Fig. 21-19. The manufacturer connects the motor windings to the terminal board, usually with quick-connect (push-on) connectors. The technician must connect the power supply voltage to the correct terminals on the board. These power supply terminals are usually of the threaded bolt and nut type, and are typically labeled L_1 and L_2. See Fig. 21-20.

One power supply wire (L_1) is connected to Terminal 1. Terminal 1 from the overload is factory connected to L_1. Terminal 3 of the overload is factory connected to a pair of push-on type terminals. These two push-ons are used to connect one end of the run winding and one end of the start winding to the overload. The overload, in turn, is connected to one side of the power supply. The other side of the run winding is connected to the other side of the power supply at L_2. Connections to the run

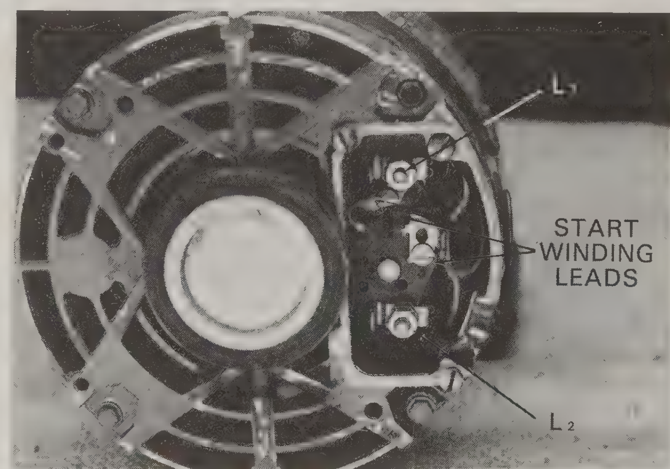


Fig. 21-19. On open-type PSC motors, the terminal board is located at the lead end. Bolt-and-nut type connections for the power supply wires are most common.

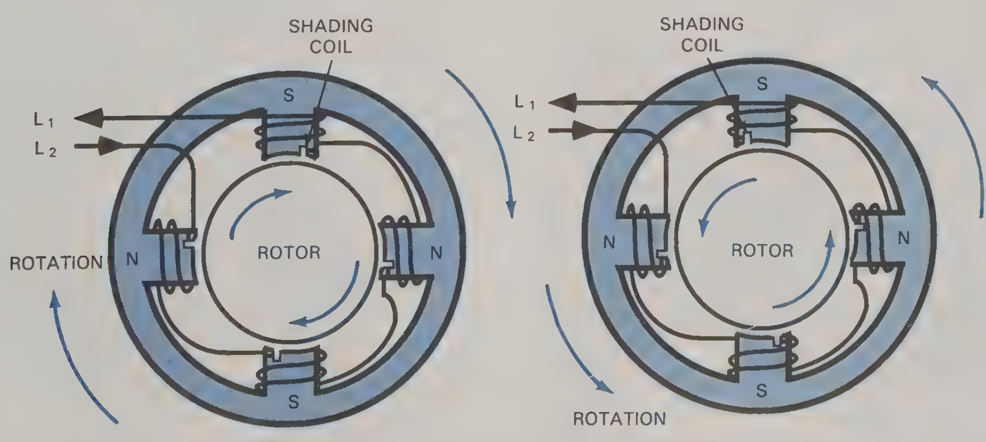


Fig. 21-18. The shaded pole motor uses small ''shading coils'' on each pole to provide the necessary impetus for starting. Direction of rotation is determined by location of the shading coils on the poles.

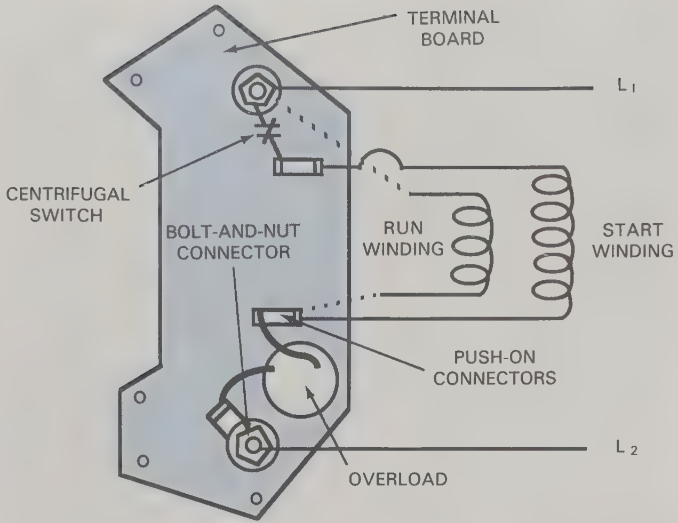


Fig. 21-20. Factory and field connections to the terminal board of an open-type PSC motor. The factory connections are made with push-on connectors (the dotted lines represent connections made behind the terminal board).

winding are now complete because it is connected from one side of the power supply to the other (parallel).

Connections for the start winding must include a ***centrifugal switch*** to disconnect that winding after start-up. The terminal board contains this electrical switch, which must be connected in series with one side of the start winding and power supply (at L_1). These connections are performed at the factory. Terminal board design and connections will vary from one manufacturer to another, but the principles remain the same.

Contacts on the centrifugal switch are normally closed (NC) when the motor is off (not running). A pair of spring-loaded weights and a connecting linkage are attached to the rotor shaft on the inside of the motor. When the motor starts and achieves 75 percent of operating speed, centrifugal force causes the weights to swing outward. The movement of the weights, transmitted by the linkage, causes the switch to open and disconnect the start winding from the circuit. When the motor stops rotating, springs pull the weights back to their normal position and the switch closes, ready for the next start-up. See Fig. 21-21.

Reversing rotation. Most manufacturers bring both wires from the start winding to the accessible part of the terminal board. These wires are different colors (identification is provided on the cover plate). Motor rotation is reversed by switching (reversing) the two terminal board connections. This reverses current flow through the start winding and the rotor follows direction of current flow.

Hermetic split-phase motor

The principles for making electrical connections to the hermetic split-phase motor-compressor are the same as those used for open-type motors. The factory makes the necessary motor connections internally to three insulated terminals extending through the hermetic shell. These terminals are: *common* (one end of each winding), *start* (other end of start winding) and *run* (other end of run winding). Because of arcing as the contacts open or close, the switch for disconnecting the start winding is located outside the shell. Connections outside the shell are made by the technician. See Fig. 21-22.

One leg of power supply (usually the white wire) is connected to the overload at terminal 1. Terminal 3 from the overload is connected to Common on the compressor. (On hermetics, the overload is always connected in series with Common.)

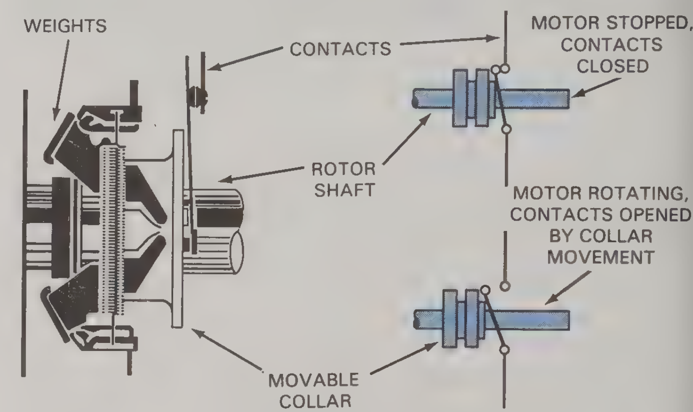


Fig. 21-21. A centrifugal switch opens when the motor reaches 75 percent of operating speed, disconnecting the start winding. As rotor shaft speed increases, the weights swing outward, sliding the movable collar along the shaft. The movement of the collar is transmitted through mechanical linkage, opening the contacts.

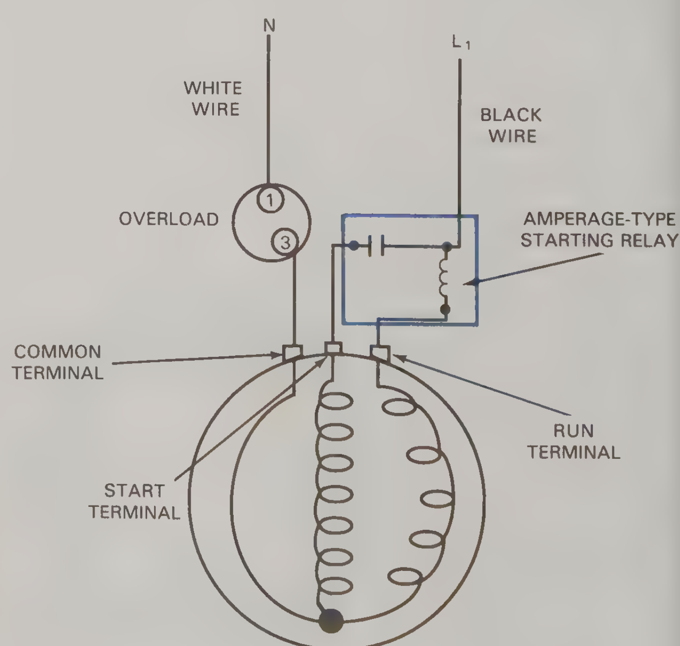


Fig. 21-22. Connections for the hermetic split-phase motor are made to the three insulated terminals (common, start, and run) extending through the shell.

The other leg of power supply (black wire) is connected to the relay and continues to the Run terminal on the shell. The start winding is connected to a switch inside the relay. At this point, it is only necessary to understand the principles involved with these connections. How these relays operate, the different types, and how they are connected are explained in Chapter 22.

PERMANENT SPLIT CAPACITOR MOTOR

The ***permanent split capacitor (PSC) motor,*** Fig. 21-23, is a split-phase motor with a design change that increases running torque. The PSC motor is used where *starting* load is low, but the *running* load is high. The higher running load would cause too much slip in a split-phase motor. To overcome the slippage problem, a method was found that uses the start winding to assist the run winding.

By connecting an electrical device known as a ***capacitor*** in series with the start winding, the magnetic field of that winding is reduced so it does not interfere with the run winding. See Fig. 21-24. The capacitor acts as a throttling (choking) device to limit the number of electrons flowing in the start winding. By eliminating the conflict of magnetic fields, the start winding can assist the run winding. This controlled use of the start winding eliminates the need to disconnect the start winding after start-up.

The name *permanent split capacitor* comes from the fact that the capacitor is a permanent part of the circuit. Since the start winding is not disconnected, the PSC motor has no need for a centrifugal switch or relay.

Run capacitor

The capacitor on PSC motors is called a ***run capacitor*** because it is used to create better running torque. However, as shown in Fig. 21-24, this "run" capacitor is connected in series with the *start* winding.

The run capacitor is an oval-shaped metal cylinder with electrical push-on type connections located on top of the cylinder. See Fig. 21-25. Capacitor size varies, and is determined by the motor manufacturer to match the operating characteristics of the PSC motor windings. When capacitor replacement is necessary, always use an *exact* replacement. Capacitors are described in greater detail later in this chapter.

Open-type PSC motor

Open-type PSC motors like the one shown in Fig. 21-23, are popular for operating larger fans and blowers. They are often used for condenser and evaporator fans. At start-up, the motor load is very low; at full speed, the fan blades are fully loaded due to the weight and volume of the air being moved. This larger load would cause a split-phase motor to slip too much, but the PSC motor solves the problem by using both the run winding and the start winding.

Reversing rotation. Reversing rotation of a PSC motor is done by changing direction of current flowing through the start winding. All that is needed is to reverse the two wires connected to the start winding.

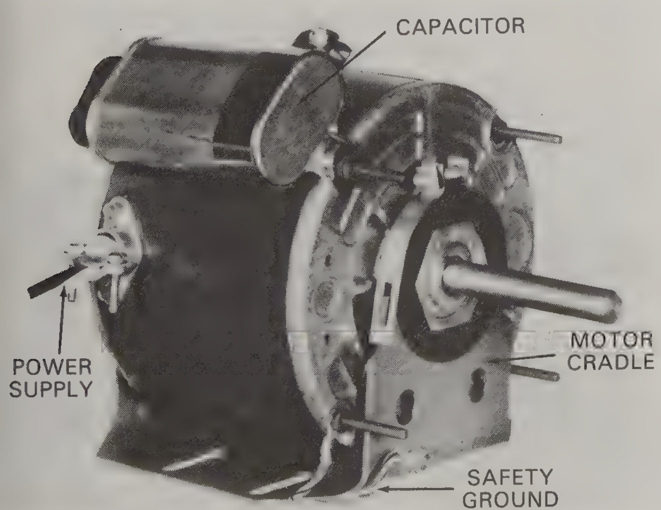


Fig. 21-23. An open-type PSC motor mounted on a supporting cradle, as it would be in many installations. The capacitor reduces the magnetic field in the start winding to allow that winding to add to the motor's running torque. (Fasco)

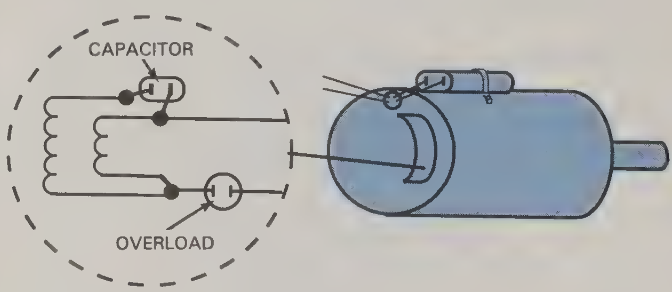


Fig. 21-24. The capacitor is wired in series with the start winding, and acts as a choke to limit electron flow through that winding. This reduces the strength of the winding's magnetic field.

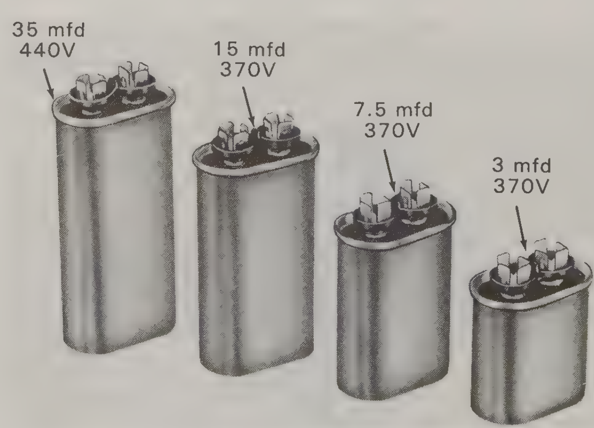


Fig. 21-25. Run capacitors are similar in appearance, but vary in size because different capacities are needed by various PSC motors. (Fasco)

Hermetic PSC motor

Hermetic PSC motors are popular for residential air conditioning systems because they use R-22 and the capillary tube type of refrigerant control. The capillary tube permits the system to "unload" (reduce head pressure) during the off cycle, which allows the use of a low-starting-torque motor. During the run cycle, however, R-22 has high head pressure, which requires the use of a motor having high running torque. The PSC motor satisfies *both* these requirements. It also eliminates the need for a relay, since the start winding is not disconnected.

Electrical connections. Connections to the PSC hermetic motor-compressor are made to factory installed insulated terminals extending through the steel shell. As shown in Fig. 21-26, one leg of power supply (white wire) is connected to the overload at terminal 1. Terminal 3 from the overload is connected to the common terminal on the hermetic. The other leg of power supply (black wire) is connected to one side of the capacitor before connection to the run terminal. The other side of the run capacitor is connected to the start terminal on the hermetic.

These connections place the motor windings in parallel (from one side of power supply to the other), with the capacitor in series with the start winding. The overload is connected in series with common.

CAPACITOR-START, INDUCTION-RUN MOTOR

The ***capacitor-start, induction-run (CSIR) motor*** is commonly used in situations where a motor must start under a heavy load, but once started can operate with just the run winding. The open-type CSIR motor is often found where V-belts are used to connect the motor to a load such as an open-type compressors or centrifugal ("squirrel cage") blower.

The capacitor-start, induction-run motor is actually a split-phase motor with a special capacitor that is used to increase current flow in the start winding. See Fig. 21-27. The excess current flow produces a much stronger magnetic field in the winding and gives greater starting torque.

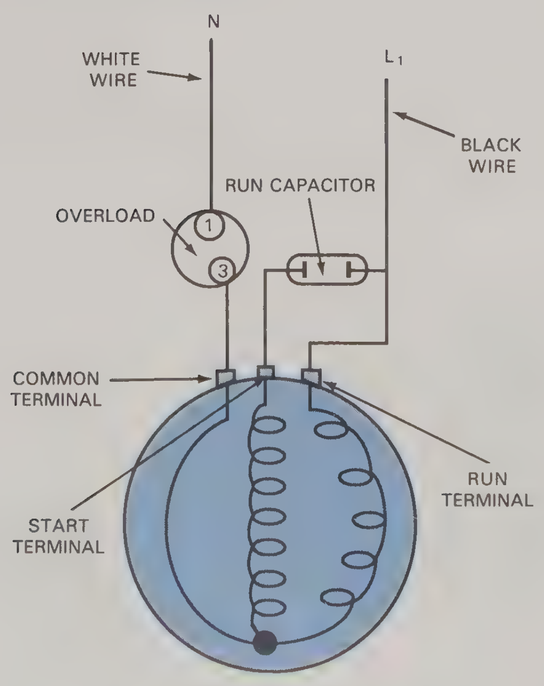


Fig. 21-26. Electrical connections for the PSC hermetic motor-compressor. Note that the run capacitor is in series with the start winding.

Start capacitor

The capacitor used on the CSIR motor is called a ***start capacitor*** because it is used to create better starting torque. The start capacitor is a cylinder of black plastic material with a hard cardboard top that holds the electrical push-on-type connections. See Fig. 21-28.

The start capacitor is not as durable in construction as a run capacitor, because it does not stay in the circuit

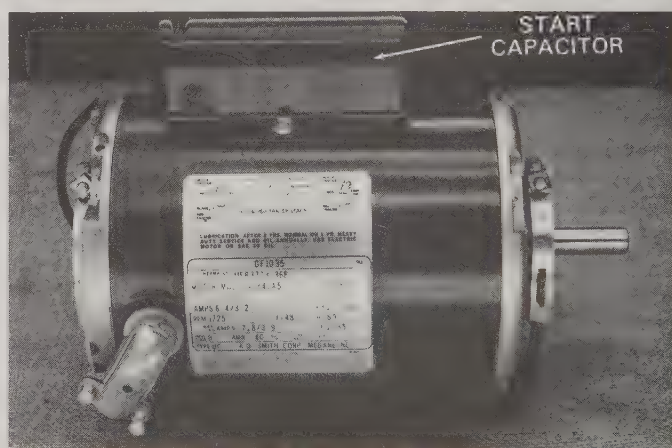


Fig. 21-27. A CSIR motor uses a capacitor to increase current flow, and thus magnetic field strength, in the start winding. This makes the motor better able to start under heavy load.

Fig. 21-28. Start capacitors are available in various sizes for different motor requirements. They are less durably constructed than run capacitors because they are used for a very brief time whenever the motor is started.

during motor operation. It is used to get the motor started, then disconnected along with the start winding. Typically, a start capacitor can withstand only about twenty starts per hour without suffering internal damage.

The start capacitor is designed to absorb (store) excess electrons during one current alternation, then discharge those electrons into the start winding when current alternates again. This increases current flow (and thus the strength of the magnetic field generated) in the start winding. The result is the necessary torque, or turning power, to get the motor started.

The size (capacity rating) of the start capacitor will determine the amount of excess electrons being discharged into the start winding. Capacitor size will vary according to horsepower rating of the motor and the load placed upon it. When you replace a start capacitor, be sure to use an *exact* replacement. Capacitors are explained in detail later in this chapter.

Electrical connections for open-type CSIR

Electrical connections for the CSIR motor are similar to those used for the split-phase motor. The only difference is the addition of a start capacitor. See Fig. 21-29. On this type of motor, the start capacitor, centrifugal switch, and start winding are connected in series. It makes no difference in which *order* they are connected, so long as they are in series so the switch can disconnect these start components from the circuit.

Reversing rotation. Reversing rotation on the open-type CSIR motor is done by swapping the two wires controlling current flow to the start winding. Information needed to identify these wires is located on the motor's data plate or inside a cover plate.

Hermetic CSIR motor

The hermetic CSIR motor is used where the compressor is required to start under loaded conditions. This occurs in systems using the automatic and thermostatic expansion valves. The compressor is often required to start when head pressure and load is relatively high.

Hermetic electrical connections. The CSIR hermetic looks like other hermetics, except the start capacitor is usually mounted immediately above (or beside) the electrical terminal box to simplify wiring connections. See Fig. 21-30.

One leg of power supply (white wire) is connected to terminal 1 of the overload. Terminal 3 of the overload is connected to the common terminal on the hermetic. The other leg of the power supply (black wire) is connected to the relay and then travels directly to the run terminal. A wire from the relay switch is connected to the start capacitor. Another wire, from the other side of the start capacitor, is connected to the start terminal.

These connections place the overload in series with common, and the run winding is connected parallel. The start winding is parallel, but the switch and start capacitor are in series with the start winding.

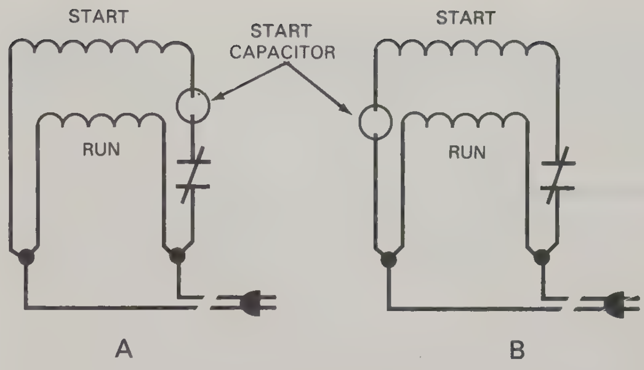


Fig. 21-29. The order of components in the start circuit does not matter, so long as they are wired in series. A–The start capacitor is between the centrifugal switch and the start winding. B–The start winding is between the switch and the capacitor.

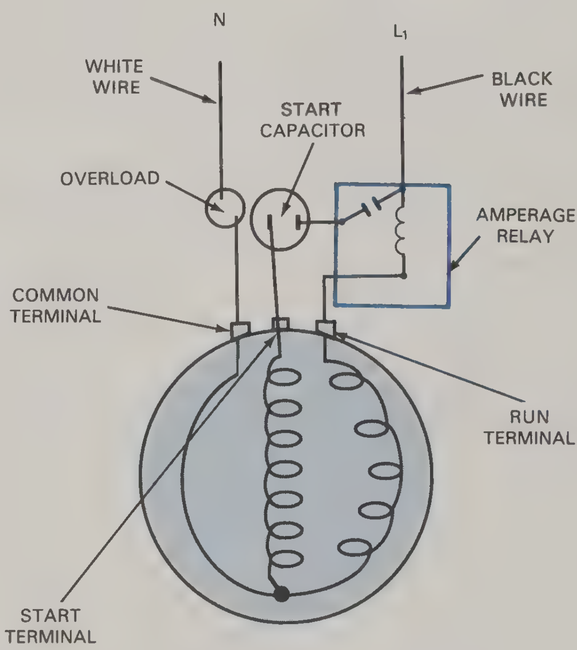


Fig. 21-30. Electrical connections for the CSIR hermetic motor-compressor. The start winding, start capacitor, and relay switch are in series.

CAPACITOR-START, CAPACITOR-RUN MOTOR

The ***capacitor-start, capacitor-run (CSCR) motor*** is another improvement on the split-phase motor. It is the most powerful of the single-phase induction motors, providing both high starting torque and high running torque. The CSCR motor is used when the motor must start under a heavy load and also must carry a heavy load during the run cycle. This motor is normally used in smaller commercial systems that have a thermostatic expansion valve.

The CSCR motor is basically a split-phase motor that combines the principles used in the PSC and the CSIR motors, using both start and run capacitors. At start-up, it operates as a CSIR motor, because of the start

capacitor. After start-up, a relay switch disconnects the start capacitor. The run capacitor *remains in the circuit* and keeps the start winding energized. The motor continues to run as a PSC.

Hermetic CSCR electrical connections

One leg of the power supply (white wire) is connected to the overload at terminal 1. See Fig. 21-31. A wire from terminal 3 of the overload is connected to the common terminal. The other leg of the power supply (black wire) is connected to the relay and directly to the run terminal. Thus, the run winding is connected from one side of the line to the other (parallel), and the overload is in series with common.

Connections from the relay and capacitors to the start winding are critical, but really quite simple. First, connect the start capacitor in series with the relay switch and start terminal. This is done by connecting a wire from the switch to one side of the start capacitor. Another wire is connected from the other side of the start capacitor to the start terminal. These connections are exactly like those used on the CSIR motor.

The run capacitor is connected to provide another circuit for the electrons to reach the start winding. This circuit must *bypass* the switch and start capacitor. These connections are called ***series-parallel*** because each capacitor is *in series* with the start winding, but they are *parallel* to each other. Such a connection permits each capacitor to act independently and perform its duty to the start winding. At start-up, both capacitors are energized. When the relay switch opens, only the start capacitor is disconnected. The circuit for the run capacitor is still available for controlled amounts of electrons to reach the start winding.

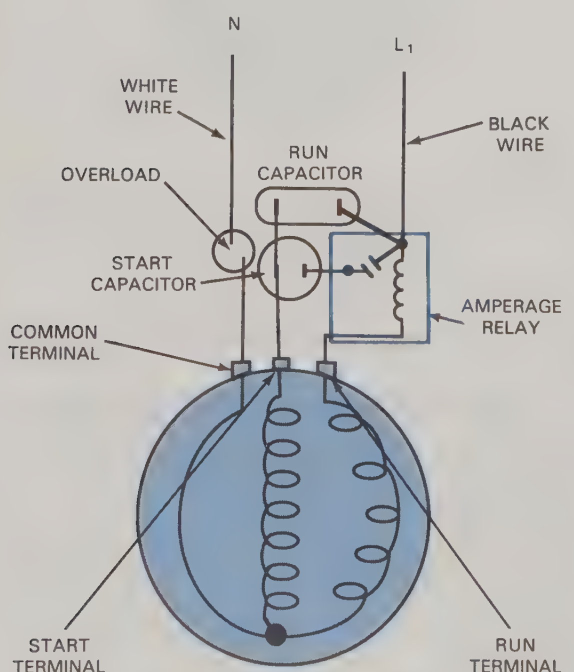


Fig. 21-31. Electrical connections for the CSCR hermetic motor-compressor. The start winding, start capacitor, and relay switch are in series. The run capacitor is wired in parallel with the start capacitor and relay switch.

CAPACITORS

A capacitor is an electrical device used to improve the operating characteristics of single-phase induction motors by increasing or decreasing the strength of the magnetic field produced by the start winding. Fig. 21-32 shows the two types of capacitors:

- **Start capacitor.** This is a dry-type capacitor intended for intermittent operation. This capacitor is fragile and will only withstand twenty starts per hour.
- **Run capacitor.** This is an oil-filled capacitor intended for continuous operation. The oil serves to dissipate any heat buildup.

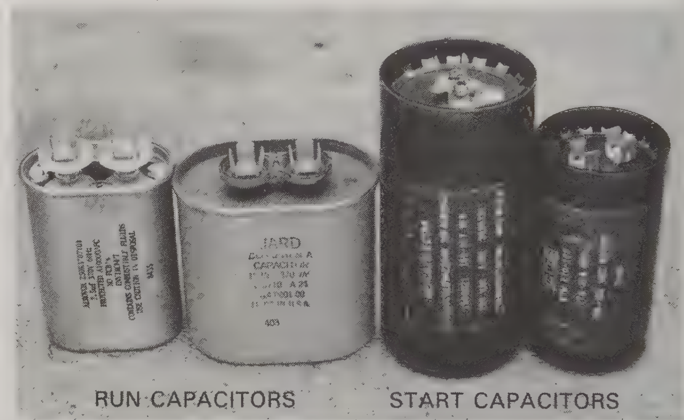


Fig. 21-32. Capacitors are of two types: run and start. Run capacitors remain in the circuit as long as the motor runs; start capacitors are energized only during motor start-up.

START CAPACITOR

The start capacitor consists of two layers of aluminum foil, called ***electrodes*** or ***plates***, that are separated by an insulating layer of specially treated paper. The foil and paper layers are about three inches wide and several feet long. They are tightly rolled into a cylinder and placed inside a black plastic case. See Fig. 21-33. A cardboard-type cover is used to seal the top, and two push-on-type electric terminals are anchored to the cardboard cover. One aluminum layer is connected to each of the terminals.

The large surface area of the aluminum layers serve as "storage tanks" for electrons. The insulating paper between the layers of foil prevents electrons from traveling from one foil layer to the other. When connected into an alternating current circuit, the applied voltage forces one side of the capacitor to fill up with excess electrons while the other side discharges its electrons. When current flow alternates (reverses), the empty side fills up while the full side discharges. See Fig. 21-34.

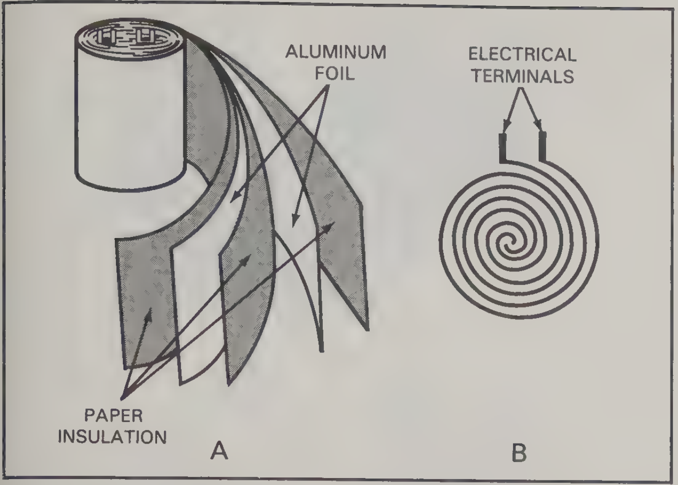


Fig. 21-33. Construction of a capacitor. A–Long strips of aluminum foil, separated by strips of paper insulation, are wound into a tight coil. B–An electrical terminal is attached to each of the aluminum strips (electrodes or plates).

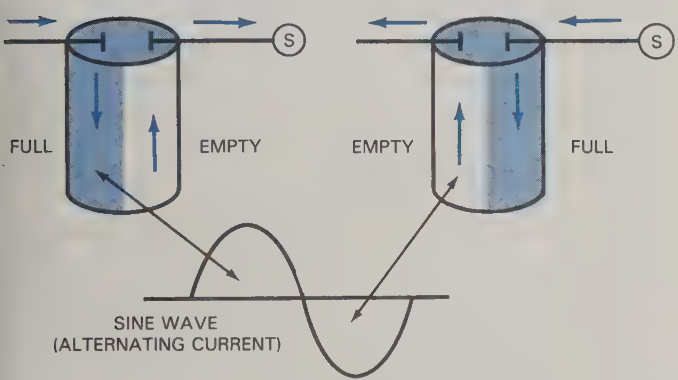


Fig. 21-34. Operation of a capacitor. When connected to an alternating current flow, the two foil electrodes alternately fill with excess electrons and discharge the electrons.

Electrons do not travel *through* the capacitor. They simply accumulate in one side of the capacitor until the current alternates, then rush out of the capacitor and return to where they came from. Electrons are constantly rushing into and out of each side of the capacitor. When one side is full, the other side is empty.

When the start capacitor is connected in series with the start winding, one side of the capacitor is discharging its excess electrons into the winding. This procedure increases the current flow in the start winding, which greatly strengthens the magnetic field and produces better starting torque. The other side of the capacitor discharges back into the supply wire.

Capacitor malfunctions

Both sides of the capacitor must be able to function, or the movement of electrons will stop (no current flow). The movement of excess electrons into and out of the capacitor will cause the capacitor to become hot. If a start capacitor is not removed from the circuit rather quickly, it will suffer a burnout or becomes shorted. A ***shorted capacitor*** is one in which the aluminum coils are permitted to touch. A burnout, or ***open capacitor*** occurs when one of the terminals becomes separated from its coil.

The start capacitor is a frequent source of motor problems. Anything that causes the motor to ***short-cycle*** (turn on and off frequently) will cause the start capacitor to burn out. If the motor tries to start and cannot, the capacitor remains in the circuit and burns out.

Bleed resistor

Sometimes a 20,000Ω, 2W solid-state resistor is soldered in place to connect the capacitor terminals, Fig. 21-35. This resistor does not interfere with normal capacitor operation. During the off cycle, the resistor permits electrons trapped in one side of the capacitor to slowly migrate ("bleed over") to the empty side until the two sides are equal. A resistor used in this way is called a ***bleed resistor.*** It serves a two-fold purpose:

1. It protects the technician by preventing an electrical shock that could occur from touching the terminals of a charged capacitor.
2. It prevents the excessive arcing that would otherwise occur when relay contacts close after a very short run cycle. Such excessive arcing can cause relay contacts to weld together, or destroy the contact.

RUN CAPACITOR

The run capacitor is constructed like the start capacitor, with some important differences. The run capacitor is better built and is almost troublefree because its capacitance rating is low and it must remain in the circuit. The case is heavy gauge metal, which helps dissipate heat. The aluminum foil strips are shorter and thinner, and the coil is wound less tightly. This limits the amount of electron movement in the capacitor. A major difference is that the run capacitor is filled with a ***dielectric*** (insulating) oil that helps transfer heat from inside the capacitor to the metal case.

Manufacturers of outdoor condensing units for residential air conditioning systems sometimes install a run capacitor having three terminals. This is actually

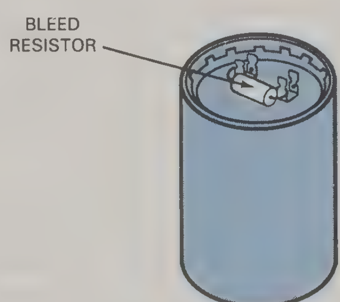


Fig. 21-35. A bleed resistor is a safety feature, preventing an electrical shock that could occur from touching the terminals of a charged capacitor. It also helps reduce arcing of relay contacts.

two run capacitors in one case. This cost-saving procedure is possible because the compressor and condenser fan are both PSC motors. The rating for each capacitor is listed on the case. One terminal of the capacitor is identified as common to each capacitor, and this terminal is connected to power supply. Another terminal is marked F (fan) and connected to the start winding of the fan motor. The other terminal, marked H (hermetic), is connected to the start winding of the compressor.

CAPACITOR RATINGS

Both start and run capacitors have two important ratings. One of these is *VAC* (volts, alternating cycle), and the other is ***microfarads*** (mfd or μ f).

The voltage rating of a capacitor indicates the nominal voltage at which it is designed to operate. Using a capacitor at voltages *below* its rating will do no harm; excessive voltage, however, will cause severe damage. Run capacitors must not be subjected to voltages that are more than 10 percent higher than their nominal VAC rating. Start capacitors must not be subjected to voltages more than 30 percent above their nominal VAC rating. Start capacitors are normally rated at 110VAC or 250VAC, and run capacitors are normally rated at 370VAC. The 370VAC rating makes allowance for the counter-emf generated by the start winding.

The amount of energy that a capacitor can store is expressed in microfarads. This rating tells how much "kick" the capacitor delivers to the start winding. Start capacitors have much higher microfarad ratings than run capacitors. Run capacitors are available from 1.5 mfd to 50 mfd, while start capacitors can be purchased in ranges from 75 mfd to 600 mfd.

Capacitors are selected according to the size of the motor and the load placed on the motor. Replacement capacitors should have exactly the same microfarad and voltage ratings as the one being replaced. If exact replacement is not possible, the new capacitor's microfarad rating should be 5 to 10 percent greater than that of the one being replaced.

CAPACITOR SAFETY

Older run capacitors used polychlorinated biphenyl (PCB) as the dielectric oil. This fluid is dangerous. If the metal shell is accidentally pierced or opened, do not touch the fluid or breathe the fumes. Disposal of such run capacitors should be done only by properly trained technicians.

The start winding of a motor can be damaged by a shorted and grounded run capacitor. This damage can be avoided by proper connection of the run capacitor. The electrical terminal attached to the aluminum foil closest to the metal case is usually identified with a special marking, Fig. 21-36. Power supply should always be connected to the identified terminal. This is the terminal most likely to short to the metal case and be grounded in the event of a capacitor breakdown. If the capacitor should break down and become grounded, the power supply line will blow a fuse before the motor is damaged.

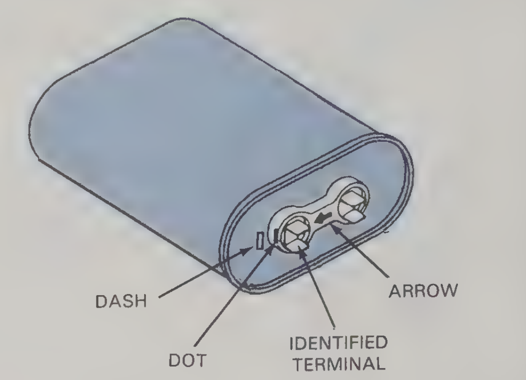


Fig. 21-36. The terminal connected to the outer aluminum strip is marked on a run capacitor. The power supply should connect to this lead to help protect the motor. Some manufacturers use a dot; others prefer an arrow or a dash. Typical locations of these marks are shown.

TESTING CAPACITORS

One method used to test a capacitor is to replace the possibly faulty capacitor with a known good one. If the motor operates properly, the old capacitor was faulty.

Both start and run capacitors can be tested with an ohmmeter. The capacitor must first be disconnected from the circuit, then discharged by shorting across the terminals, using a screwdriver with an insulated handle.

Touch the two leads from the ohmmeter to the capacitor terminals. If the capacitor is good, the meter battery (9VDC) will slightly charge one side of the capacitor. When the leads are reversed from one terminal to the other, one side of the capacitor will discharge into the meter and the other will absorb electrons from the battery. Each time the meter leads are reversed, the meter needle will deflect slightly and immediately return to zero. (A digital ohmmeter will show a slight resistance reading, then return to zero.) Deflection of the needle is very slight because the meter battery is very weak when compared to normal line voltage. Increasing meter resistance to x 10,000 will increase needle deflection for easier reading. See Fig. 21-37.

If the ohmmeter needle deflects to an infinity reading and stays deflected, the capacitor is shorted. If the needle does not deflect at all, the capacitor is open. See Fig. 21-38. An open or shorted capacitor is faulty and must be replaced.

An ohmmeter test will not reveal a weak capacitor (low mfd capacity). This condition can only be discovered by using a tester specifically designed to test ac capacitors. See Fig. 21-39. These meters are accurate, inexpensive, and simple to operate.

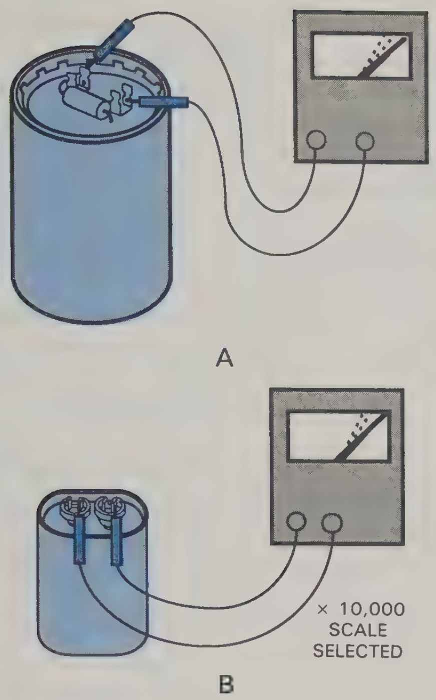


Fig. 21-37. Checking capacitors with an ohmmeter. A–Reversing leads should cause the needle to deflect slightly, then return to zero. A digital meter will briefly show a low resistance reading, then return to zero. B–The very slight needle deflection (or digital meter reading) can be increased for easier viewing by selecting the x 10,000 resistance scale on the meter.

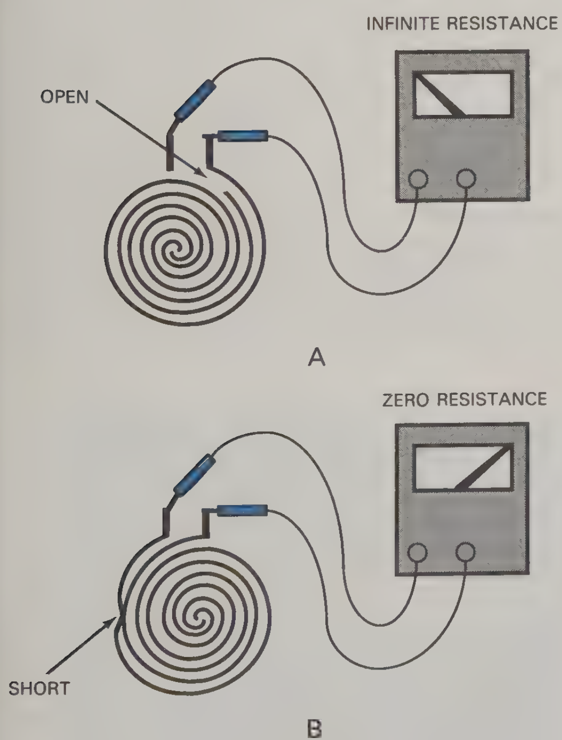


Fig. 21-38. Capacitor defects. A–An open (burned out) capacitor will cause the meter needle to deflect to an infinite resistance reading and remain there. B–A shorted capacitor will cause no deflection at all. The needle will show zero resistance. Digital ohmmeters will show the same (infinity or zero) readings.

Fig. 21-39. A tester made specifically for use with capacitors will help the technician quickly diagnose problems.

CHANGING MOTOR TYPES

It is possible to add start components to a PSC motor and convert it to a CSCR motor. This procedure is sometimes necessary when the PSC motor-compressor has difficulty starting. This problem is not unusual with residential central air conditioning systems.

Selecting of the proper size capacitor and relay is critical for proper operation. This information is available from the local dealer or compressor manufacturer. Most manufacturers of PSC motor-compressors furnish a *hard start kit* for their units motors. The kit consists of a start capacitor and relay, along with complete instructions for installation. To obtain the correct kit, the model and serial numbers of the motor-compressor are needed.

DUAL-VOLTAGE MOTORS

Some motors are manufactured to operate on either of two supplied voltages. These are called ***dual-voltage motors.*** The voltage rating on the motor data plate may read, for example, "115/230V." This means the motor can be connected to either a 115V supply or a 230V supply. Dual-voltage motors have two run windings, which must be connected properly, as shown in Fig. 21-40. For lower voltage, the run windings are connected in parallel (providing lower resistance). For higher voltage, the windings are connected in series, doubling the resistance.

The magnetic fields of the two run windings *must* rotate in the same direction. If one field is "left" and the other is "right," opposing polarities will cause the rotor to lock. The factory connects the motor windings to terminals located in the terminal box.

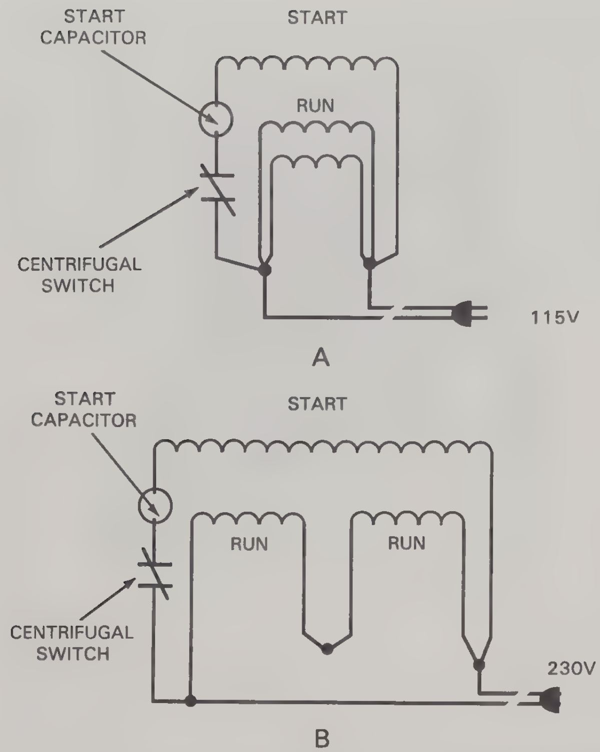


Fig. 21-40. Dual-voltage motor run winding connections. A–For the lower voltage, the windings are connected in parallel for lower resistance. B–For high-voltage operation, resistance is doubled by connecting the run windings in series.

Most dual-voltage motors are equipped with flat copper ***jumper bars*** for easy change from one voltage to the other. Instructions for placement of these jumper bars is located on the inside of the terminal box cover. Fig. 21-41 is an example of the proper placement of jumper bars on an open-type dual-voltage motor.

MULTI-SPEED MOTORS

Multi-speed motors are very common in heating, cooling, and refrigeration operations. They have several wires to consider, rather than just the two used for single-speed motors. A ***multi-speed motor*** is necessary in applications that require operation at different speeds. An example is a window air conditioner with a fan that operates at high, medium, or low speed. Many furnace blower motors are two-speed motors. The different speeds are needed because more air must be moved during the cooling season (high speed) than during the heating season (low speed).

Motor speed is determined by the number of poles in the run winding. The multi-speed motor has different ***taps*** (wires) that make it possible to select the number of poles being used. See Fig. 21-42. High speed uses two poles (3600 rpm), medium speed uses four poles (1800 rpm), and low speed uses all six poles (1200 rpm). One leg of power supply is connected to the common terminal and to the capacitor. The other side of the power supply is connected to the tap for the desired speed. Unless a selector-type switch is used, each unused tap is

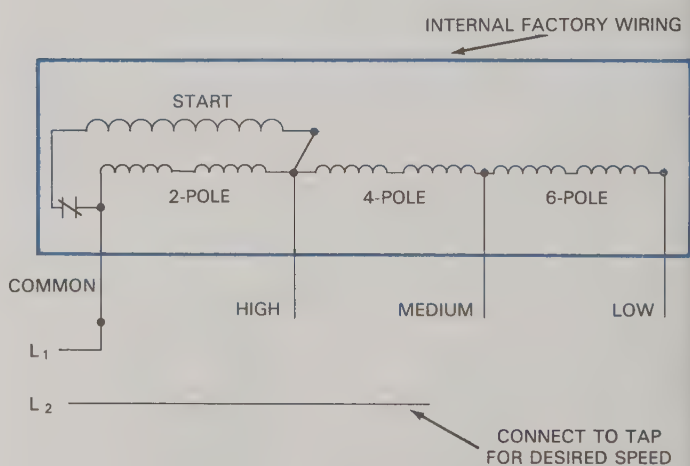


Fig. 21-42. Different numbers of poles are used for each speed on a multi-speed motor. Connections are made to the common terminal and the proper tap for a desired speed. A selector switch may be installed for ease of changing from one speed to another.

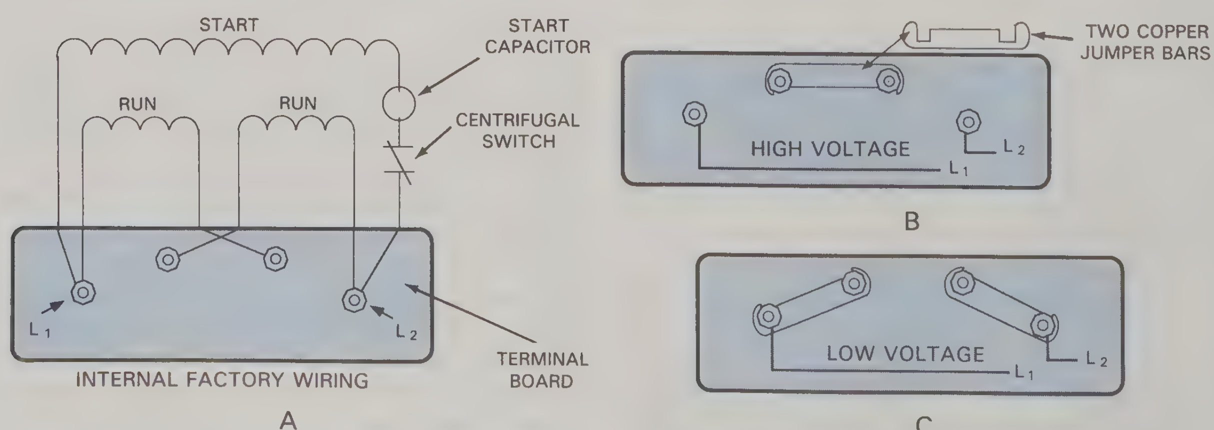


Fig. 21-41. Changing a dual-voltage motor from one voltage to another. A–Factory installed internal connections at the terminal board. B–For high voltage, the copper jumper bars will connect the run windings in series. C–Using the bars in this configuration will connect the windings in parallel, for lower resistance.

capped with a wire nut and sealed with electrical tape to prevent the motor windings from becoming grounded by the unused wires.

Only one end of the start winding is available to the technician for connection to a capacitor. The other end of the start winding is wired at the factory. This provides a power supply that is parallel to the start winding regardless of which speed (tap) is selected. Most manufacturers color code the external wires used for making connections to multi-speed motors. See Fig. 21-43 for these color codes.

THREE-PHASE MOTORS

Three-phase induction motors are common in commercial applications because they are smaller and more powerful than single-phase motors of equal horsepower. They are cheaper to operate, have fewer problems, and easy to connect and control.

Three-phase alternating current induction motors offer high starting torque and high running torque without the need for a start winding, capacitors, or relays. Only the three "hot" wires (L_1, L_2 and L_3) are needed for proper operation, but the safety ground (green) wire is included for safety. The green wire is connected to the motor frame to provide an escape for electrons if the motor becomes ***shorted to ground*** (grounded).

METHOD OF OPERATION

Three-phase motors have three pairs of stator poles (windings), one pair for each supply wire. Each winding shows identical resistance. A three-phase motor has three stator poles. As shown in Fig. 21-44, each stator pole has a North pole and a South pole, located directly opposite each other. This is called "one pole per phase." The stationary poles are equally spaced around a circle, exactly 60° apart ($6 \times 60 = 360$ degrees).

With three-phase alternating current, the three power supply wires will take turns changing polarity from North to South to zero. When one wire is North, another wire is South, and the third wire is zero. See Fig. 21-45. This changing of polarity in the supply wires produces a strong rotating magnetic field. The alternating zero does not produce polarity in the stator poles, which permits the other two poles to produce the rotating push-pull effect on the rotor. Because the zero pole is constantly rotating around the stator poles, the rotor will chase the rotating magnetic fields.

The alternation of North, South and zero in a three-phase motor produces a strong starting torque and strong running torque. If the motor is running and one wire is disconnected from the circuit, the motor may continue to run as a single-phase motor. However, when the motor shuts off, it cannot restart. This is called "single-phasing."

TAP	COLOR
COMMON	WHITE
HIGH	BLACK
MEDIUM	YELLOW
LOW	RED
CAPACITOR	PURPLE (2 WIRES)

Fig. 21-43. Table shows colors used by manufacturers to code wires used when making external connections to multi-speed motors.

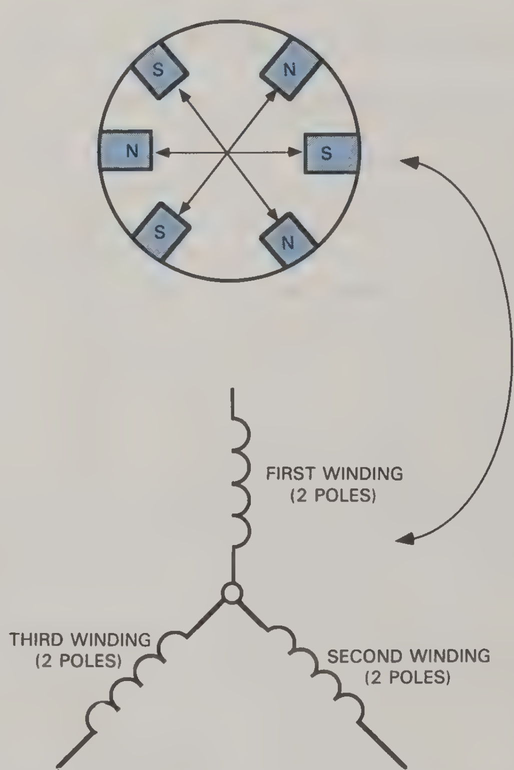


Fig. 21-44. The three windings, or stators, of a three-phase motor each have a North pole and a South pole. The stators are equally spaced around a circle.

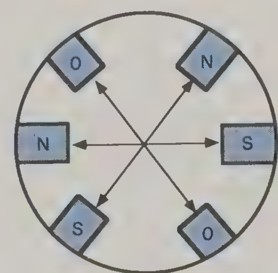


Fig. 21-45. The three poles will change polarity, in turn, from North to South to zero, producing a rotating magnetic field for the rotor to "chase."

Changing rotation

Direction of rotation is determined by direction of the rotating zero, where no polarity is being generated. A three-phase motor is easily reversed by changing any two supply wires. This causes the zero to rotate in the opposite direction.

Resistance of windings

All the windings in a three-phase motor are identical in resistance. One end of each winding is factory connected inside the motor, which provides an ideal location for the internal overload. When this overload opens, all three wires are disconnected at the same time. See Fig. 21-46. When reading resistance between any two motor leads, the ohmmeter is actually reading through two windings. The resistance reading between any two wires should be the same.

DUAL-VOLTAGE THREE-PHASE MOTORS

Many three-phase motors are of the dual-voltage type. The motor data plate specifies the voltages (220/440V, for example) that can be applied. Instead of three wires to connect, however, this motor will have *nine* wires. The nine wires are tagged and numbered from 1 to 9 for easy identification. Never remove these numbers!

This motor contains an extra set of three poles. Two wires for each of these extra poles is brought outside the motor, in addition to the three original wires. See Fig. 21-47 All nine wires must be connected. The motor windings are connected in parallel for low voltage, and in series for high voltage.

Instructions for connecting the nine wires for each voltage are normally included on the motor data plate. These instructions are accurate, but each manufacturer uses different methods to explain the connections.

A simple Y-type diagram can be constructed, as shown in Fig. 21-48, for connecting this motor for either voltage. Draw a "Y" and put extensions on each of the branches, allowing a small space between the extensions. Each line represents one of the stator windings. The next step is to number all the ends. Start numbering with 1 on any outside branch and continue numbering around the "Y" in clockwise rotation, working constantly toward the inside, until all ends are numbered.

The three power supply wires are always connected to motor terminals 1, 2, and 3. Except for direction of rotation, it does not make any difference which supply wire is connected to which terminal, since the supply wires are the same.

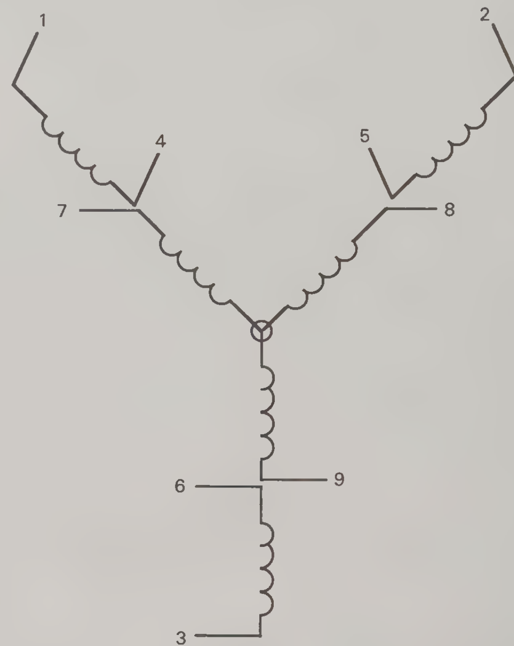


Fig. 21-47. A schematic of dual-voltage three-phase motor windings, showing how the nine wires are connected to provide the rotating magnetic field needed for operation.

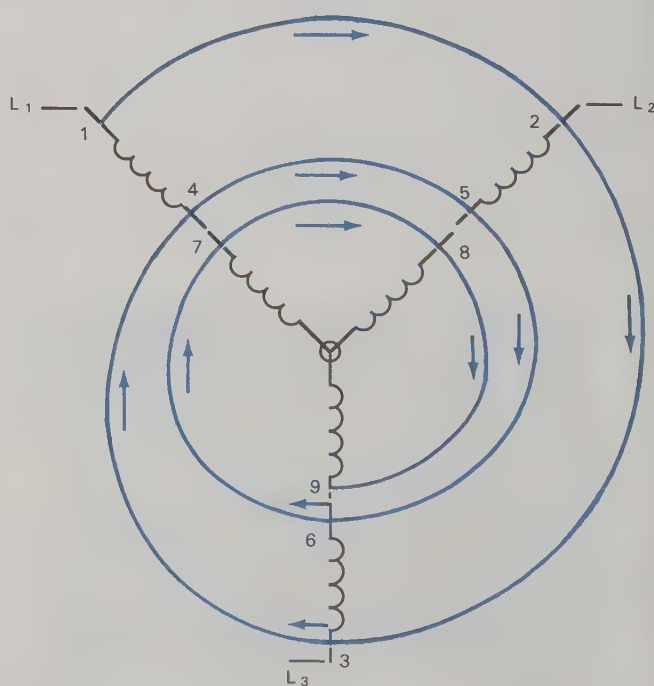


Fig. 21-48. Constructing a "Y" diagram for dual-voltage three-phase wiring connections. The spiral arrow shows the sequence for numbering the ends of the windings.

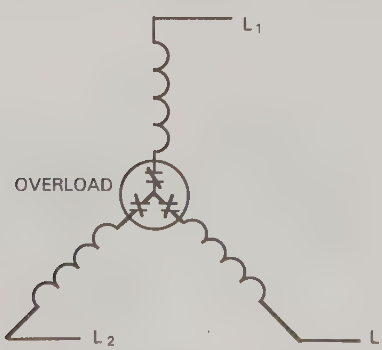


Fig. 21-46. All three windings are connected to the internal overload, so that when the overload opens, all the windings are disconnected.

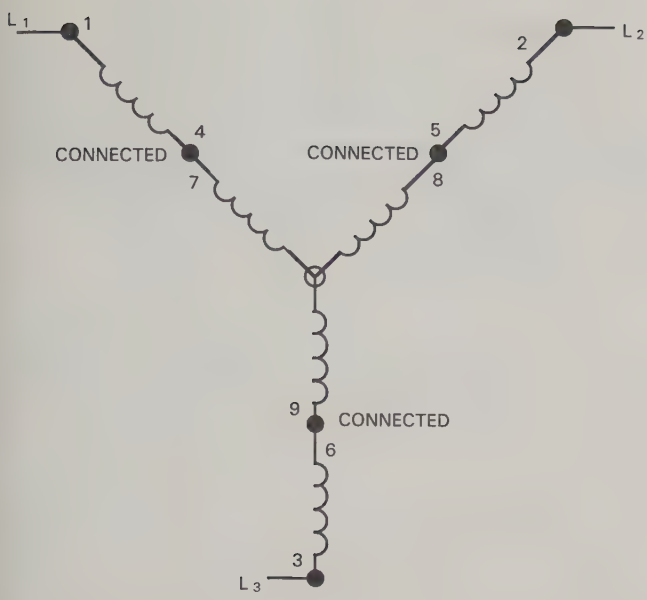


Fig. 21-49. The high-voltage connection places the windings in series. Wires 4 and 7 are connected, as are wires 5 and 8, and wires 6 and 9.

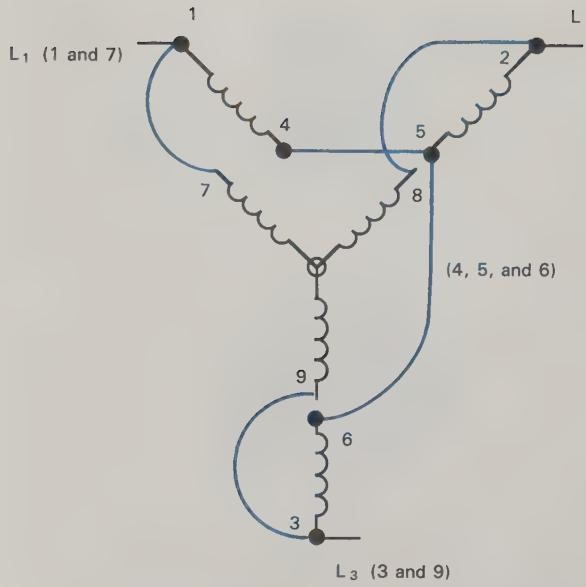


Fig. 21-50. The low-voltage connection places the windings in parallel. There are three wires at each connection, compared to two wires in the series connection for high voltage.

High-voltage connection

The higher voltage connection is easy because the windings are wired in series and the branches in the diagram are simply connected to form a larger "Y." See Fig. 21-49. Wires 4 and 7 are connected together, 5 and 8 are connected together, and 6 and 9 are connected together. The power supply wires are *always* connected to 1, 2, and 3. For high voltage, there are two wires at each connection and the current must flow through four windings before being able to exit via another supply wire. Each of the wire connections should be made with a wire nut and secured with electrical tape.

Low-voltage connection

The parallel hook-up for low voltage is more complicated, but the principle of the "Y" is still used. As shown in Fig. 21-50, L_1 is connected to 1 and 7, L_2 is connected to 2 and 8, L_3 is connected to 3 and 9, and 4, 5, and 6 are connected together.

For low voltage there are three wires at each connection and the current flow is through two windings before being able to exit via another supply wire.

Resistance check of windings

The motor windings on a three-phase motor can be checked with an ohmmeter. If a resistance reading of zero occurs, the motor is shorted. If a reading is obtained from any motor lead to ground, the motor is grounded. A reading of infinite resistance (full scale deflection on an analog meter) shows that the winding is open. In each of these cases, the motor must be rewound or replaced.

Depending upon the size of the motor, resistance readings on three-phase motor windings will range from 1 to 50 ohms (the larger the motor, the smaller the resistance.) On a single-voltage three-phase motor, all windings will have the same resistance. On the dual-voltage three-phase motor, the three "extra" windings will all have one-half the resistance of the main windings.

IDENTIFYING COMPRESSOR TERMINALS

Most manufacturers of single-phase hermetic motor-compressors mark the three electrical terminals as C, S, and R, or Common, Start, and Run. If these terminals are *not* marked, they can be identified by checking the resistance of the windings. This procedure is also used to identify motor problems.

Electrical power supply to the motor must be disconnected and the connections to the three motor terminals must be opened. This isolates the motor windings and prevents backfeed from other electrical circuits that would cause a false ohmmeter reading.

The first test with the ohmmeter is to determine which two terminals have the highest resistance. This requires three separate readings to cover all the possible combinations. The two terminals that produce the highest reading (18 ohms in the example) will be the start and run terminals, because the meter is reading through both windings (in series). By process of elimination, this high reading means the other terminal is the common terminal. See Fig. 21-51.

With the common terminal identified, read from common to each of the other two terminals. Common-to-start will show more resistance than common-to-run. See Fig. 21-52. The approximate start winding and run winding resistance readings for fractional horsepower single-phase motors are presented in table form in Fig. 21-53.

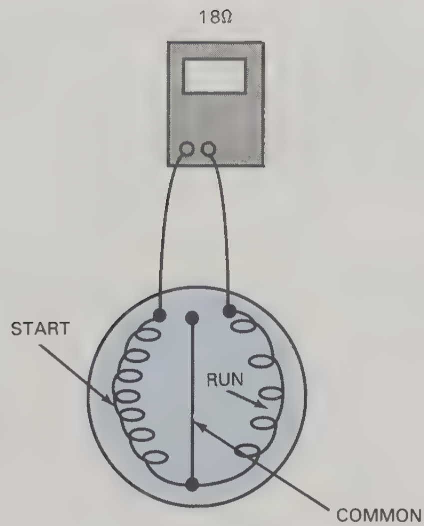


Fig. 21-51. The highest of the terminal-pair resistance readings will be for the start and run windings. By process of elimination, the remaining terminal is the common.

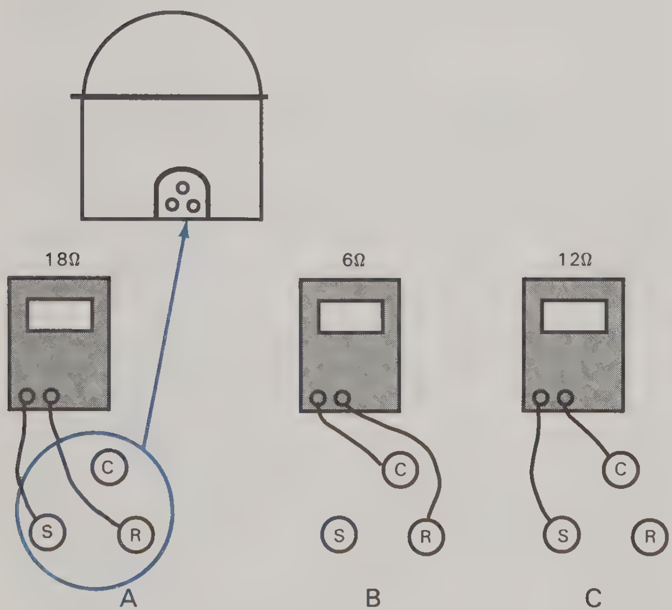


Fig. 21-52. Identifying terminals by measuring resistance. A–The common terminal is the one remaining when the highest terminal pair (run/start) reading is obtained. B–A reading from common to run will yield the lowest reading. C–The common to start reading will fall between the other two.

HP	RUN WINDING	START WINDING
1/8	4.5	16
1/6	4.0	16
1/5	2.5	13
1/4	2.0	17

Fig. 21-53. This table shows run and start winding resistances, in ohms, for common sizes of fractional horsepower single-phase motors.

IDENTIFYING MOTOR PROBLEMS

The ohmmeter is used to check motor windings. This process is sometimes called "ringing out" a motor. To check motor windings with an ohmmeter, all electrical connections to the motor must be removed to prevent false readings and possible damage to the meter.

GROUNDED WINDINGS

Each motor terminal must be checked to determine whether it is *shorted to ground*. Use one of the ohmmeter probes to scratch through paint or oxidation on the steel shell of the hermetic unit. This will provide a good electrical connection. Connect the other ohmmeter lead to one of the motor terminals (C, S or R). This ohmmeter reading should be infinity (unlimited resistance). See Fig. 21-54. A reading of zero resistance, or less than infinite resistance indicates a winding that has become shorted to ground. Repeat this test for each motor terminal. A "grounded" hermetic is not repairable, and must be replaced.

A motor with a winding that is shorted to ground is usually indicated by a blown fuse, or by cycling on the overload. As described earlier, cycling on the overload occurs when the motor attempts to start, but trips the overload each time. Because the overload is more temperature-sensitive than a fuse, the overload may open before the fuse blows.

OPEN WINDINGS

An ***open winding*** refers to a broken wire in the motor winding that is *not* touching the motor shell. To locate or determine an open winding, the motor must be checked with an ohmmeter. Check each winding by touching the meter probes to two terminals and noting the reading. Repeat for each pair of terminals until all combinations have been checked. See Fig. 21-55. Since there is no complete path (circuit) for current flow if the circuit is open, the resistance indicated by the meter would be infinity. An open can occur in either winding, or in the common connection. This condition is not repairable in the field, so the hermetic must be replaced.

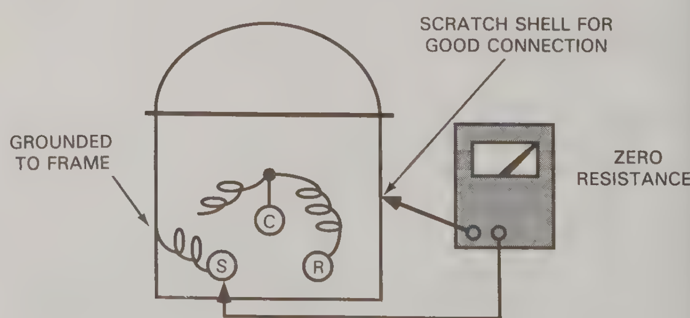


Fig. 21-54. A short to ground is indicated by a zero resistance reading when the ohmmeter probes are touching the hermetic case and a motor terminal. The hermetic must be replaced.

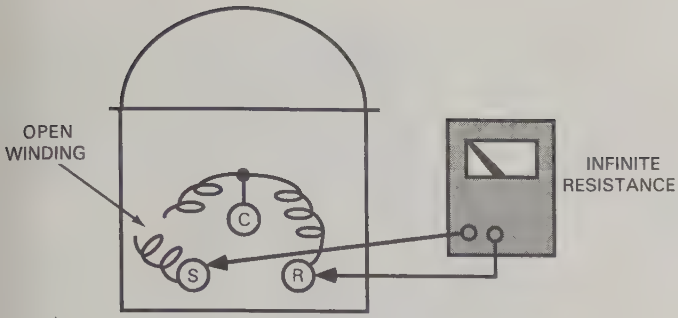


Fig. 21-55. An infinite resistance reading when the meter probes are touching two motor terminals indicates an open winding. The hermetic must be replaced.

MOTOR BEARINGS AND LUBRICATION

The primary cause of motor failure is dry bearings, which can cause the rotor to drag, lock up, or wear out. Dry bearings cause excess amperage draw. Worn bearings cause the motor to be noisy.

All motors have a ***bearing*** (lubricated support for a rotating shaft) located inside the end bell (cover) at each end of the rotor. The rotor shaft is inserted through the bearing which holds the shaft in perfect alignment. This alignment is *critical* because the air gap between the rotor and stator is only a few thousandths of an inch, and must be equal on all sides. The end bells are held in position by four bolts that extend through the stator shell from end to end.

PERMANENTLY OILED BUSHINGS

Many bearings used for fractional horsepower motors are permanently lubricated. The bearing is actually a ***bushing*** (sleeve around a shaft) made of porous bronze that is saturated with oil at the factory. This bushing is considered to be permanently lubricated and is often used in fan motors and other low-horsepower applications. No additional oiling of the bearing is required for the life of the motor.

OIL-TYPE BEARINGS

Oil-type bearings should receive three to six drops of oil in each oil port about every six months. Over-oiling should be avoided, since excess oil may accumulate in the stator and collect dirt. The oil ports are located at each end bell of the motor for direct access to the bearing. See Fig. 21-56. The oil ports are normally capped with rubber or plastic plugs to keep dirt out of the bearing. These plugs are easily removed for adding oil and should always be replaced. Regular 10W30 nondetergent automotive oil is used to oil motor bearings.

GREASE-TYPE BEARINGS

Most larger horsepower motors have ball bearings that are lubricated with grease, rather than oil. A grease fitting (called ***zerk fitting***) is installed on top of each bearing and a removable plug located at the bottom of each bearing. See Fig. 21-57. An ordinary grease gun is used to pump high grade medium grease to these bearings about every three months. The bottom plug must be removed before pumping grease into the bearing. If it is not, pressure can rupture the diaphragm located on the inside of the bearing area that is used to hold grease in the bearing. A ruptured diaphragm will permit grease to enter the rotor area and results in a dry bearing.

Removing the bottom plug prevents any pressure on the diaphragm because new grease forces old grease (if any) out the bottom port. Continue pumping until new grease appears at the bottom port. This usually requires only two or three pumps on the grease gun. If the bearing requires more pumps on the gun, the diaphragm has probably been ruptured and grease is entering the motor. A ruptured diaphragm is usually revealed by a grease stain or puddle immediately under the motor. The bottom plug should always be re-installed after greasing the bearing. A motor with a ruptured diaphragm must be greased frequently to delay or prevent bearing failure.

FANS AND BLOWERS

Fans and blowers are essential parts of most refrigeration and air conditioning systems. Two types of blades are used to move air:

- ***Axial*** (propeller) blades are used for fans.
- ***Centrifugal*** (squirrel cage) blades are used for blowers.

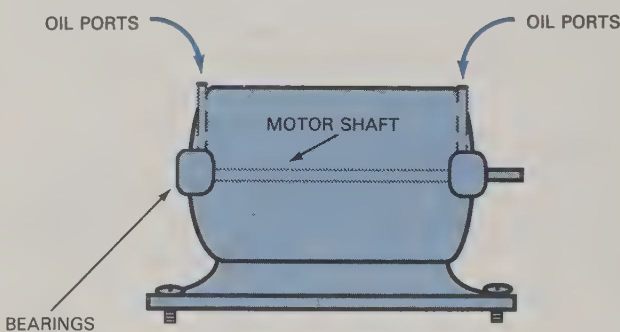


Fig. 21-56. Oil ports are located atop the bearings at each end of the motor. Periodic lubrication is needed to prevent motor damage.

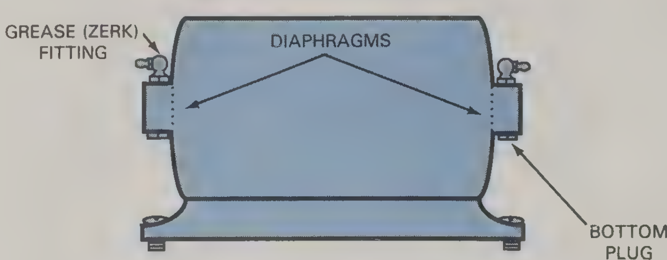


Fig. 21-57. Grease fittings are used to force lubricant under pressure into a bearing. Bottom plug must be removed when adding grease to prevent rupturing the diaphragm and allowing grease to leak out of bearing.

FANS

The purpose of any fan is to move a specific volume of air at a specified ***velocity*** (speed). The amount of air moved (volume) is measured in ***cubic feet per minute (cfm)***. The air volume that a fan can move is determined by several factors. If any one factor is changed, the volume of air moved also changes. These factors are:

- Speed of rotation.
- Number of fan blades.
- Blade pitch (angle, in degrees).
- Blade length.
- Blade width and shape.

Axial blade types

There are two types of propeller (axial) blades, *round* and *square*. See Fig. 21-58. Each type serves a definite purpose. The round blade is best suited for free air applications, such as pedestal fans. It does not perform well when required to operate against pressure. To obtain proper air flow, the inlet air and discharge air flow must be unrestricted. The round blade has excellent efficiency in free air conditions, and is almost noiseless because the air enters and exits at different angles along the blade length.

The square-type propeller blade is designed to operate against medium and high pressure, in such applications as evaporators and condensers. The discharge blade tip is at full diameter, which provides an air seal at the corners. The square blade fan is very efficient when placed in a cowling or orifice that surrounds the blade tips. A clearance gap of about 1/4 in. is permitted between the blade tips and the orifice.

Fan blade rotation

Proper rotation of a fan blade is determined at the factory and cannot be changed in the field. Most propeller-type blades are mounted directly onto the motor shaft, so the rotation of the fan blades must match the rotation of the motor.

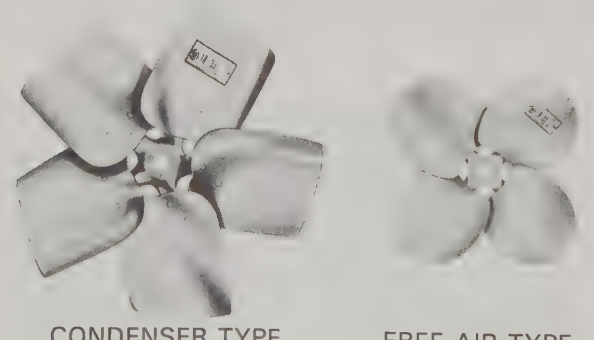


Fig. 21-58. Round blades and square blades are used for different applications. Square blade fans are used in most air conditioning applications.

Rotation of fan blades is said to be clockwise (CW) or counter-clockwise (CCW) as viewed from the discharge air side. Rotation for draw-type fan blades (those that pull air back over the motor) must be viewed from the motor side. Rotation for blow type fan blades must be determined from the front of the blades, with the motor behind.

Most fan blades are not designed to be reversed (mounted backward) to obtain desired rotation. Reversing a fan blade will cause severe reduction in air volume moved, increase motor and fan blade fatigue, and cause system problems. It is always best to replace a fan blade with an exact duplicate, but some allowance is permitted. The pitch can vary two degrees either way without trouble. Substituting four blades instead of three blades will add very little to the air volume moved.

A motor and fan must be properly matched to obtained desired results. Motor speed and direction of rotation are important. The motor shaft must precisely fit the hole in the fan hub to prevent slipping or wobbling. The fan is usually anchored to the motor shaft by one or more set screws through the hub between the blades and the motor.

When purchasing fan blades, the supplier must know the rotation, number of blades, degree of pitch, hub hole size, blade type (square or round), and diameter (from blade tip to blade tip).

CENTRIFUGAL BLOWERS

Centrifugal blade (squirrel cage) blowers are used in applications where airflow is controlled and directed by ducts, such as furnaces and central air conditioning units. Excess airflow causes pressure to build up inside the duct. This air pressure inside the duct is called static pressure and assures an even distribution of air to all vents. As duct pressure increases, the volume of air delivered by the fan is reduced. The centrifugal blower is sized to deliver enough air flow to maintain proper static pressure levels.

Centrifugal blowers are measured by blade length and the diameter across the blade wheel. Some blowers are mounted directly on the motor shaft (direct drive); others are belt-driven. See Fig. 21-59. Direction of rotation is determined by the forward curvature of the blades. Forward-curved blades are designed to cup incoming air and throw this air forward by centrifugal force.

SUMMARY

This chapter explained the six basic types of induction motors commonly used by the industry. Each type of motor was explained separately. Induction motors have many similarities, but the principle of operation differs for each type. Single-phase and three-phase motors require different connections to accomplish specific purposes. Automatic start-up involves a start

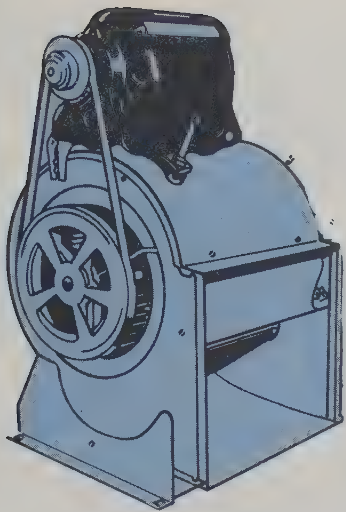


Fig. 21-59. Belt-drive blowers are common in heating and air conditioning installations. (Lau)

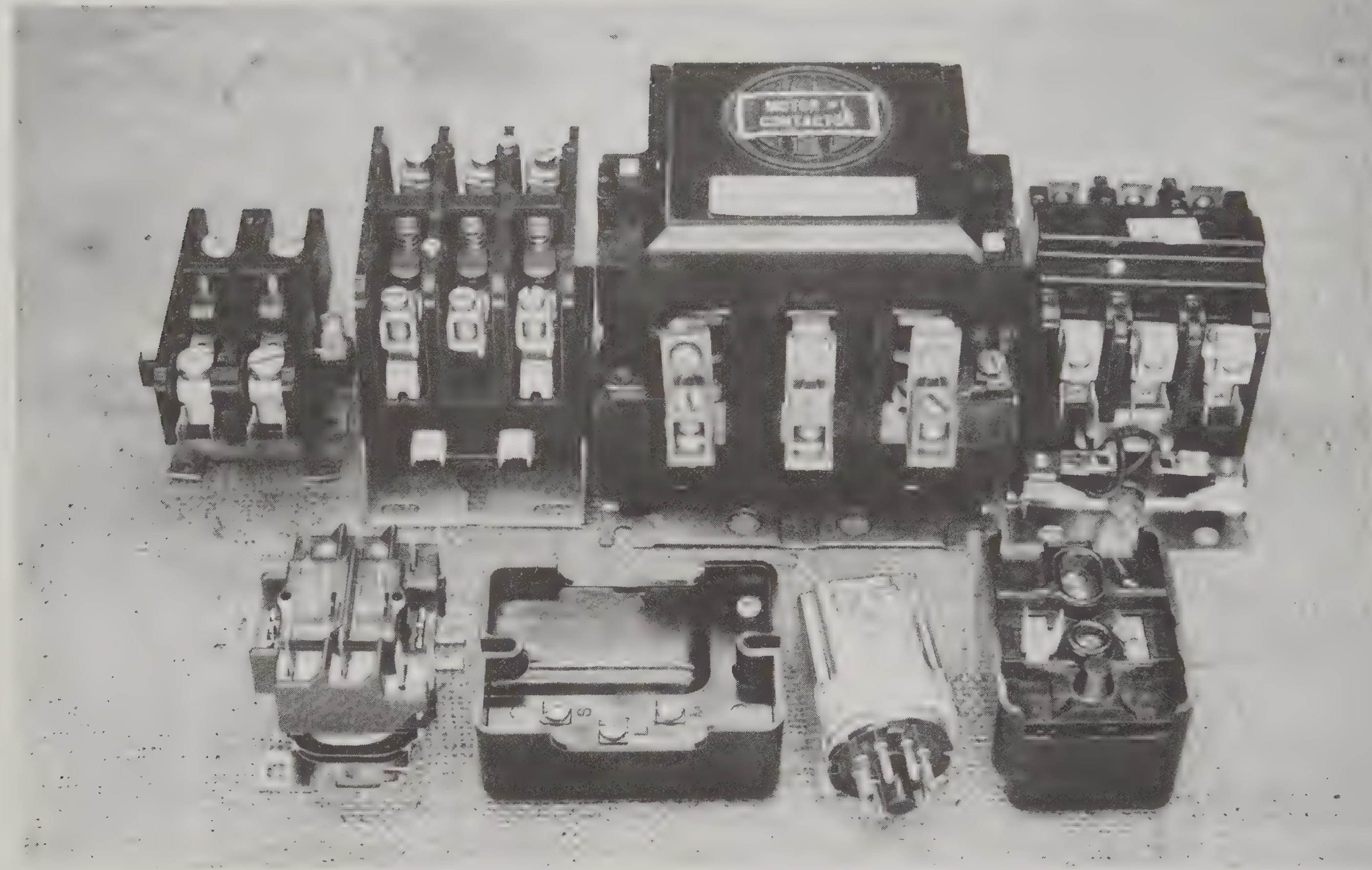
winding and start components. Troubleshooting procedures require sufficient knowledge of each type of motor. Information on reversing rotation and on how to connect dual-voltage and multi-speed motors was provided.

The chapter included information on the proper lubrication of motor bearings was explained. The purpose, styles, and types of fans and blowers were explained, along with the importance of proper air movement to heating, refrigeration, and air conditioning systems.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name two main parts of an electric motor.
2. The motor windings are located in the ________.
3. True or false? An opposed magnetic field is produced in the rotor by a process called induction.
4. Motor speed is determined by the number of stator ________.
5. Name the two most common motor problems.
6. True or false? The start winding has no other purpose than to provide automatic starting of an electric motor.
7. Which of the motor windings determines direction of rotation?
8. The start winding must be disconnected at about ________ percent of normal motor speed.
9. LRA and FLA are abbreviations for:
10. Cycling on the overload can be caused by:
    a. Excess amperage draw.
    b. Excess motor heat.
    c. Excess compressor heat.
    d. All the above.
11. Name five types of single-phase induction motor.
12. The only difference between a split-phase motor and a CSIR motor is the:
    a. Centrifugal switch.
    b. Relay.
    c. Start capacitor.
13. On hermetics, the switch used to disconnect the start winding is located outside the shell, due to:
14. Name the three electrical terminals located on an hermetic.
15. The PSC motor uses a:
    a. Start capacitor.
    b. Run capacitor.
    c. Relay.
16. Capacitors are always connected in ________ to the start winding.
17. Name three methods to check a capacitor.
18. True or false? Dual-voltage motors have two separate run windings.
19. What test meter is used to check a motor for a short to ground or open winding?
20. How is the direction of rotation changed on a three-phase motor?



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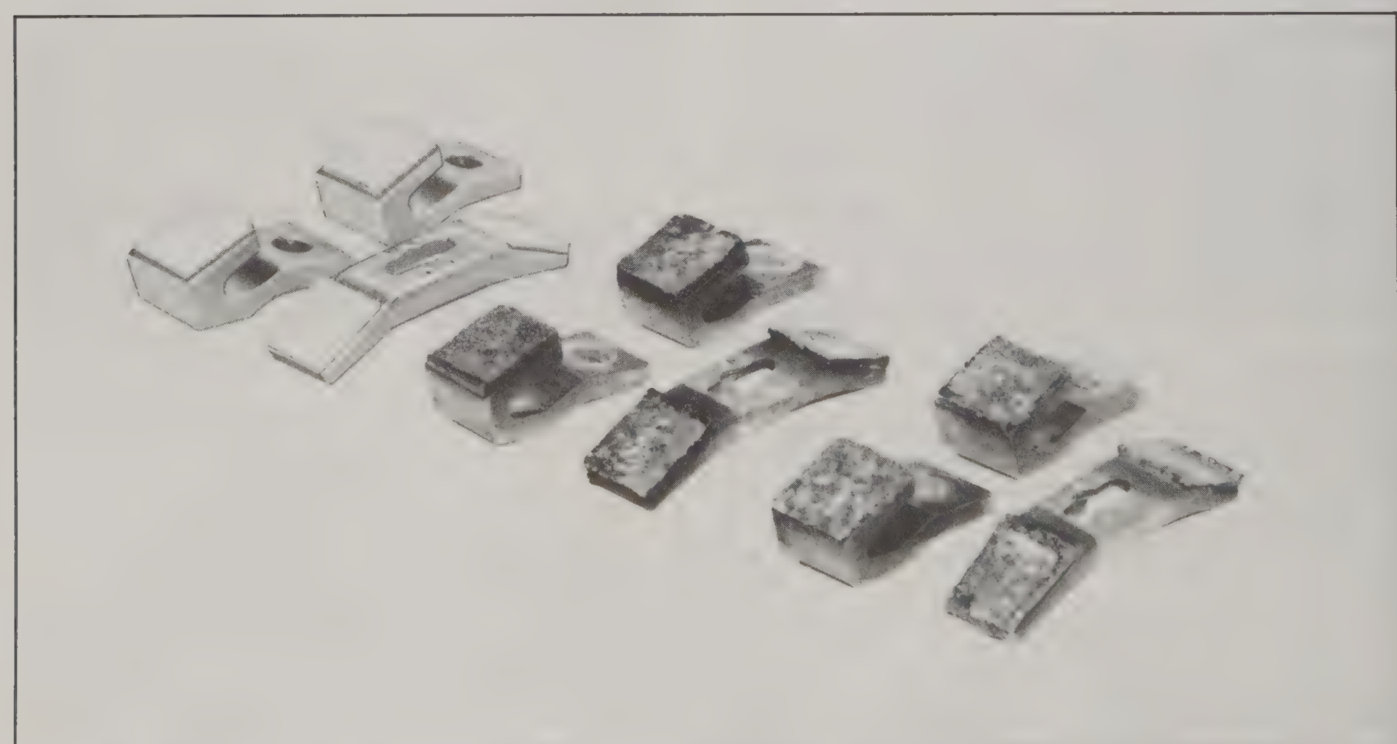


B

Electromagnetic control devices, such as relays and contactors, are vital to operation of HVAC equipment. A–Contactors (top) and relays (bottom) are available in sizes to handle different system requirements. B–Contacts in some devices are replaceable. The set at the left is new, the one in the middle shows normal wear, and the set at the right exhibits severe pitting that would require replacement.

Chapter 22

ELECTROMAGNETIC CONTROL DEVICES

After studying this chapter, you will be able to:
- *Use and troubleshoot solenoid valves.*
- *Recognize and troubleshoot relay circuits.*
- *Connect and troubleshoot contactors and line starters.*
- *Read and use both pictorial and schematic diagrams.*

NEW WORDS

amperage relay	line starter
armature	lockout
contactor	magnetism
control circuit	pickup voltage
cycling on the overload	pictorial diagram
disconnect	positive temperature coefficient (PTC) ceramic thermistor
dummy terminals	relays
electrical symbols	schematic diagram
electromagnetism	solenoid valve
ferrous metals	start capacitor
hard-start kit	voltage relay
induced magnetism	
jumper wire	
ladder diagram	

MAGNETISM

An important magnetic principle is that a magnetized object can induce ***magnetism*** in certain other metals. ***Ferrous metals*** (metals containing iron) will readily accept magnetism. It means that they will become a magnet if placed within a magnetic field (lines of flux). This is called ***induced magnetism.*** *Soft iron* is easily magnetized, but quickly loses its magnetism when the magnetic field is removed. This feature makes soft iron ideal for making electromagnets (magnets that can be turned on and off). Electromagnets are used in many electrical devices, such as motors, relays, and solenoids.

ELECTROMAGNETISM

When current is flowing through a conductor (wire), a magnetic field is generated around the wire. This is called ***electromagnetism.*** When the wire is wrapped into the form of a coil, the magnetic field becomes stronger. If the wire is coiled around a rod (core) of soft iron, the wire's magnetic field will induce magnetism in the iron. See Fig. 22-1. Magnetism in the core is controlled by starting (or stopping) current flow in the coil.

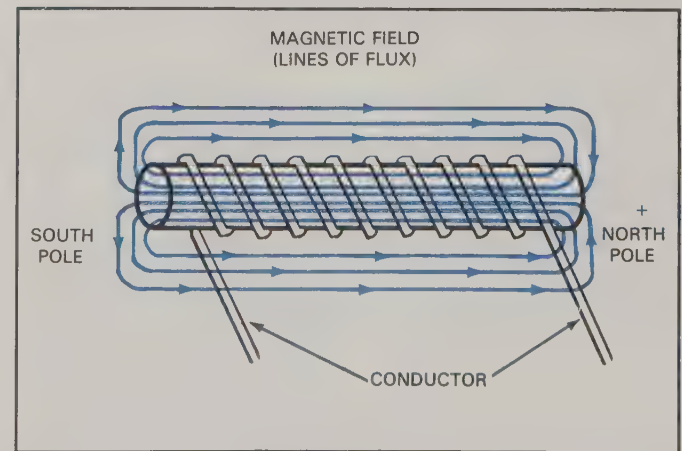


Fig. 22-1. When current flows through a wire coil wrapped around an iron core, the iron is magnetized. The magnetic field can be turned on or off by turning the electric current on or off.

Turning off electrical supply to the coil kills the magnetic field in both coil and core.

As the electric current alternates, polarity of the magnetic field around the wire (and coil) also alternates. With 60 cycle current, polarity alternates from north to south 120 times per second. The induced magnetism in the core is always opposite in polarity to that of the coil. This electromagnetic principle is used in operating solenoid valves, relays, contactors, and line starters.

ELECTROMAGNETIC CONTROL DEVICES

Electromagnetism is used to operate a number of control devices used in various applications such as the opening and closing of valves, motor starting, and circuit control.

SOLENOID VALVES

Electromagnetism is often used to control the opening and closing of valves. These electrically operated valves are called solenoid valves. See Fig. 22-2.

A ***solenoid valve*** uses an electrical coil to control a movable core (plunger). The coil magnetism induces opposite polarity in the iron plunger. Because opposite magnetic poles attract, the plunger is lifted into the coil's magnetic field. This opens the valve, which will remain open so long as the coil is energized. When the coil is deenergized, magnetism disappears and the plunger returns to the closed position. See Fig. 22-3.

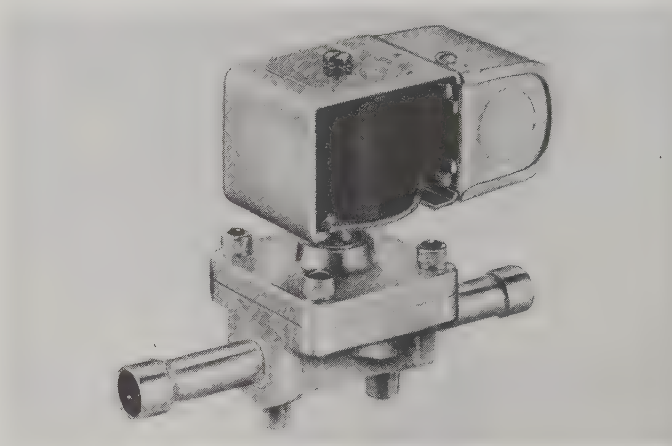
Solenoid valves are frequently used on applications where automatic control of liquids is desired. Some type of switch is required to control power supply to the solenoid coil. Fig. 22-4 shows how proper liquid level is automatically maintained in a tank by using a float switch to control a solenoid valve. When the liquid level falls, the float closes the switch. This energizes the solenoid coil, opening the valve and permitting liquid to flow into the tank. When the proper liquid level is reached, the float opens the switch, cutting off power to the solenoid valve and allowing the valve to close.

RELAYS

An internal centrifugal switch cannot be used for hermetic motor-compressors, due to arcing of the switch contacts. The arcing would cause breakdown of oil and refrigerant into acid and destroy the motor windings. Exterior starting ***relays*** are used to disconnect the start winding on single-phase motors and contactors are used for starting and stopping three-phase motors.

The relay is an electrically operated switch that can be used to automatically disconnect the start winding and/or the start capacitor of a motor. There are just two types of relays, amperage and potential. Each type is easily recognized. The method of operation and the electrical connections of the two are very different.

A relay opens or closes switch contacts. It does so using the same electromagnetic principle as the solenoid: a coil of wire is wrapped around an iron core located near a movable arm, or ***armature.*** An electrical contact is installed at one end of the movable arm, and a matching fixed contact below the arm.



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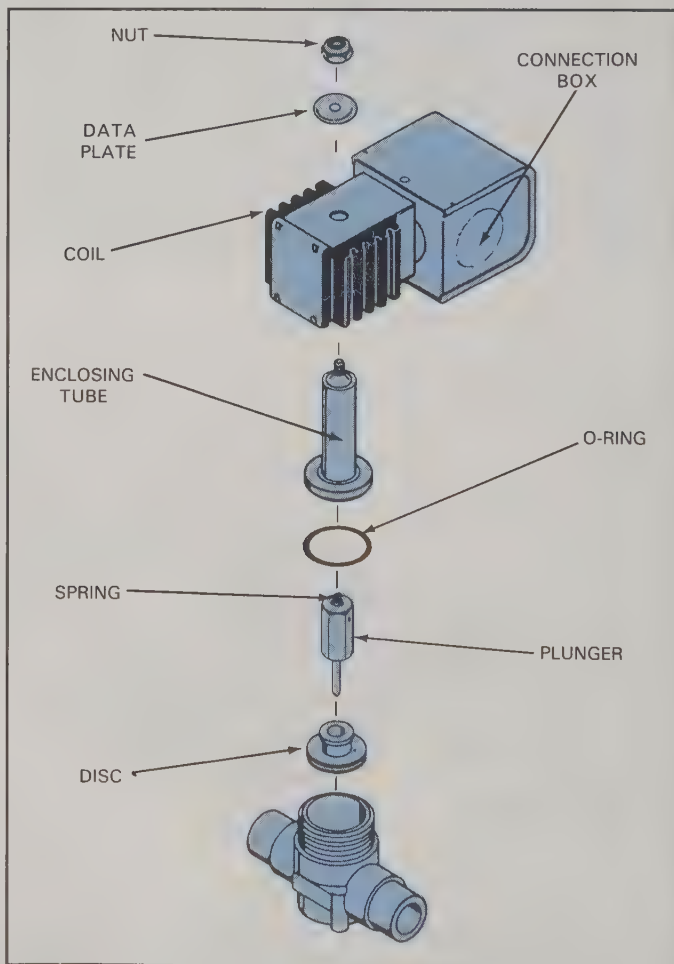


B

Fig. 22-2. Solenoid valve. A–A typical solenoid valve has the coil mounted on top of the valve body. (Parker Hannifin) B–Exploded view of a solenoid valve. (Sporlan Valve Co.)

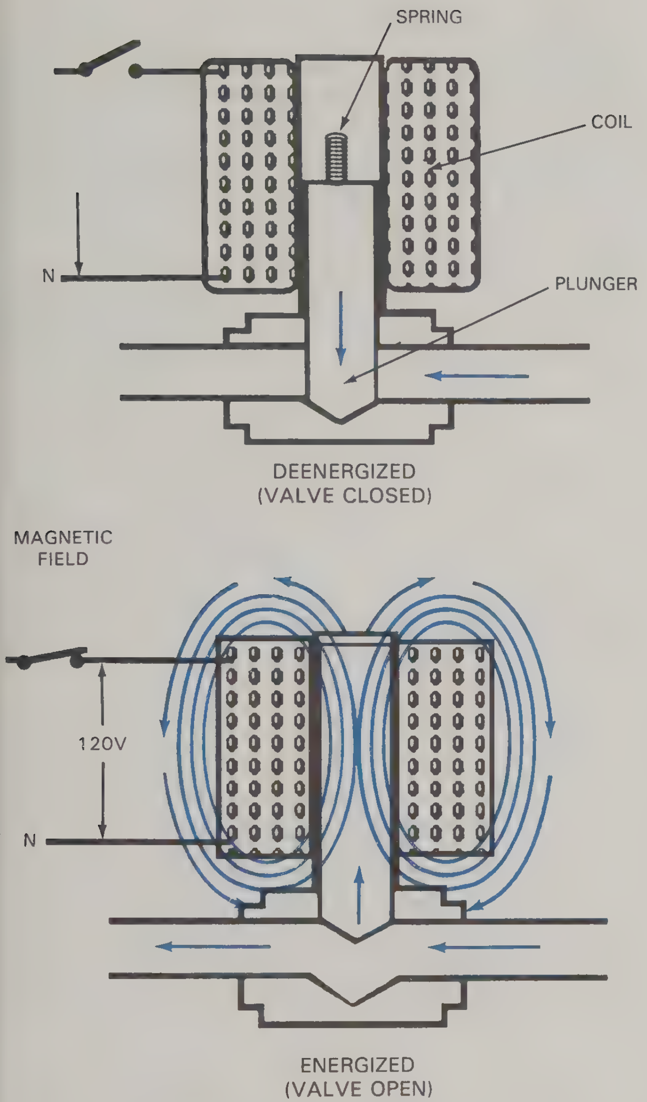


Fig. 22-3. When the solenoid coil is energized, the opposing polarities pull the plunger upward, opening the valve. The valve will remain open until the coil is deenergized.

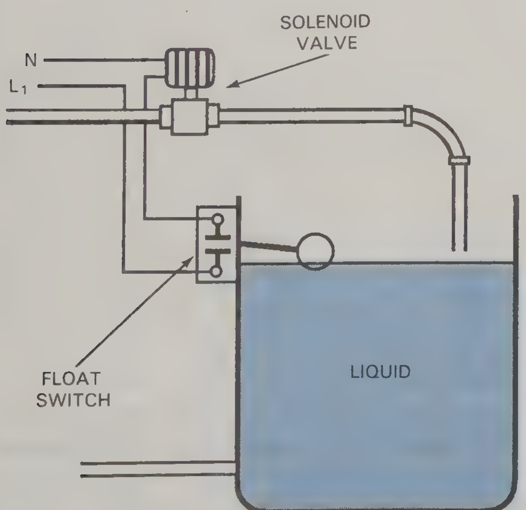


Fig. 22-4. A float switch controls current flow to the solenoid valve, opening and closing it as needed to automatically maintain the liquid level in the tank.

Relay operation

When the relay coil is energized, magnetism is induced in the core, pulling the movable arm downward. This causes the contacts to close. When the relay coil is deenergized, a spring returns the arm to its original position, opening the contacts. See Fig. 22-5.

The electrical circuit to the coil is entirely separate from the circuit through the contacts. See Fig. 22-6. This separation permits use of a low-voltage (24V) circuit to open or close a line-voltage (120V) circuit. In such an application, the low voltage circuit is referred to as a ***control circuit.***

The relay contacts have low current ratings, with a maximum of 10A being considered normal. Current flow in the *relay coil circuit* is even lower (often less than

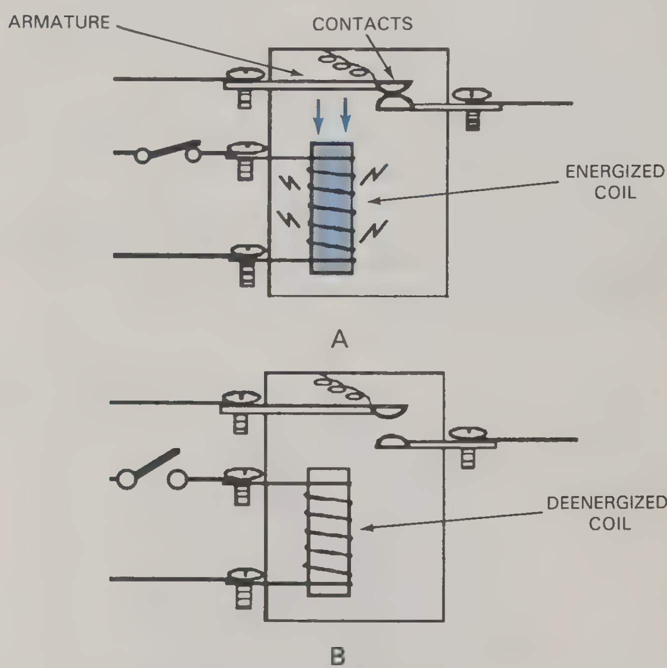


Fig. 22-5. Relay operation. A–When the coil is energized, the armature is pulled downward, closing the contacts to complete a circuit. B–When the coil is deenergized, a spring pulls the armature upward again, opening the contacts.

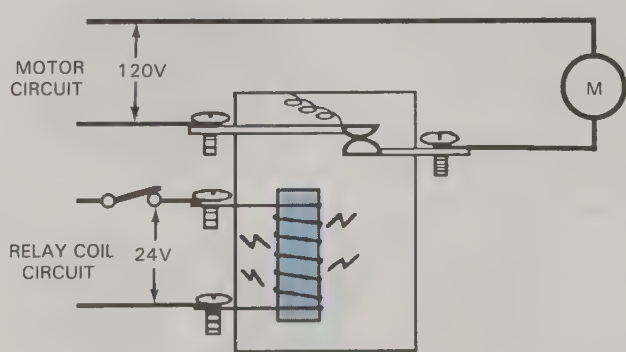


Fig. 22-6. The 24V circuit for the relay coil is electrically separate from the 120V motor circuit that it controls. The use of a low-voltage circuit to control a higher-voltage circuit is common in appliances and in heating and cooling equipment.

1/4 ampere). The low voltage (24V) used in the control circuit is safer for the technician, permits the use of small wire, and is less likely to cause a fire. Also, switches last longer due to less arcing of the contacts.

The relay case often has a schematic (electrical drawing) or symbols for electrical components that reveal the internal operation of contacts and coil terminals. See Fig. 22-7. The relay data plate reveals coil voltage and amperage rating of the contacts. Relays often contain more than one set of contacts. It is not uncommon, for example, to find relays used in applications requiring 10 or 12 poles per device. On a schematic, relay contacts are always shown in the state that they assume when the coil is deenergized: normally open (NO) or normally closed (NC). All sets of contacts will change position at the same time when the coil is energized. See Fig. 22-8.

A relay is often used to control an electrical load from a remote location. For example, a 120V motor located in a basement could be controlled from the building's second floor by using a relay. The relay coil could be 24V, permitting the use of small wires in the control circuit. Fig. 22-9 shows both pictorial and schematic views of such a system. Schematic drawings are often used to illustrate electrical circuits. Schematics do not show the *size* or *length* of wires.

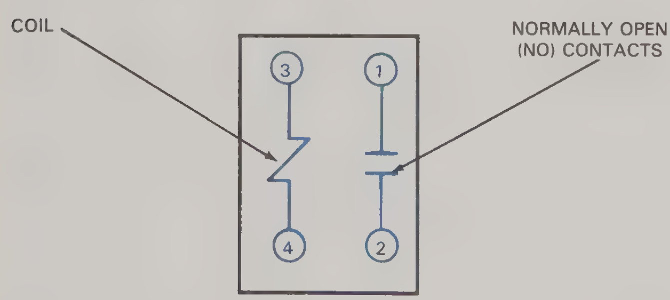


Fig. 22-7. Symbols like these are often used to depict relay components on schematics.

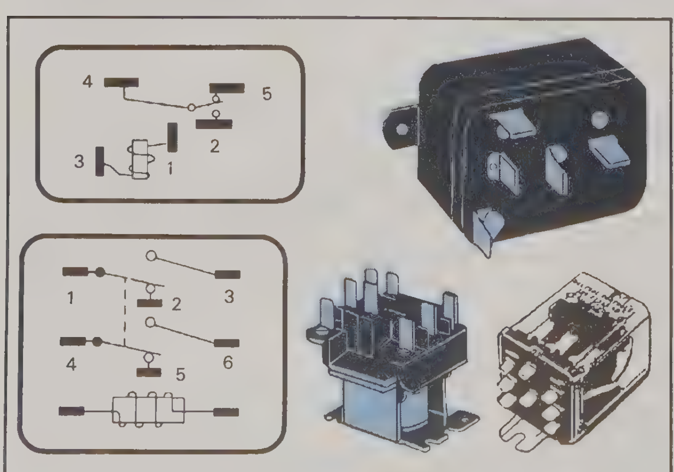


Fig. 22-8. A relay can have a number of contacts to control different devices simultaneously.

Amperage relays

When a single-phase motor starts, current flow to the run winding is very high. The rotor is not moving and the resistance of the run winding is very low. As the rotor begins to turn, the amperage (current flow) will decrease as a result of increased resistance created by counter-emf. This principle of temporary high current flow to the run winding at start-up can be used to operate a relay.

Relay contacts. The contacts on amperage relays are *normally open (NO)*, with the plunger located below them. The plunger must lift up to close the contacts and

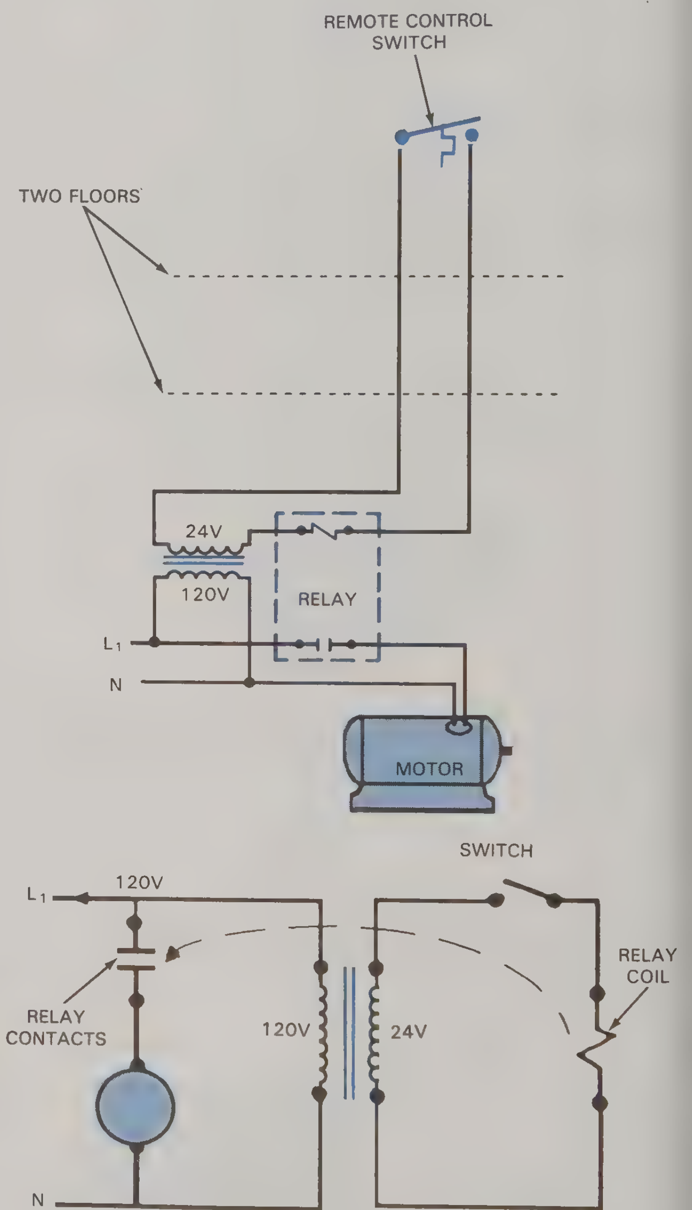


Fig. 22-9. A relay can be used in a low-voltage control circuit that operates a distant device. As shown in the pictorial view at top, a motor is located two floors below the remote control switch. When the switch is closed, it energizes the relay coil, closing the contacts in the 120V motor circuit. The circuit is shown in schematic form at bottom. Note that the schematic shows voltages and symbols for all devices and conductors, but does not show size or length of the conductors.

complete the circuit to the motor's start winding. Once the start winding is energized, the rotor quickly speeds up. As it does so, counter-emf is generated and current flow through the run winding decreases. When the rotor speed reaches 75 percent of normal, amperage through the run winding drops and the magnetic field generated by the relay coil weakens. The plunger is pulled downward by gravity, opening the contacts to the start winding. See Fig. 22-10.

The contacts used on amperage relays must be durable, because of the arcing that takes place as they open and close under high-current-flow conditions. Arcing can burn out contacts or weld them together.

Push-on amperage relays. Most amperage relays are designed for mounting directly onto the compressor terminals at R and S, as shown in Fig. 22-11. These are push-on type relays, with the mounting procedure assuring an upright position. Electrical connections are simplified because the relay makes direct contact with the terminals.

This type of relay is normally used on the split-phase hermetic compressor. Connection is easy, with the relay simply being pushed onto the compressor's R (run) and S (start) terminals. The relay contacts are between R and S, while the coil is connected to the R terminal on the compressor and the L (line) terminal on the relay housing. The technician merely connects the black (hot) wire to the L terminal. The overload is mounted inside the terminal box and already connected by a short wire to the compressor's Common terminal. The technician connects the Neutral (white wire) side of the power supply to the overload.

Other amperage relays. Some amperage relays (known as *thermal* relays) are totally enclosed in a plastic case that is not mounted directly on the compressor. If the relay is position-sensitive, the word "up" and a directional arrow often will be printed on the case, Fig. 22-12. Also printed on the case will be letters designating the terminal screws: L (line, or power supply), S (start winding), and M (main, or run winding). The contacts inside the relay are always between M and S, and the coil is connected between L and M.

Some amperage relays have extra terminals designated by *number*. These are *dummy terminals* that have no effect on the operation of the relay. Instead, they serve as a convenience to the technician by providing connection points for splicing wires. They eliminate the need for wire nuts and electrical tape. Use of the dummy terminals is optional.

A typical use for dummy terminals is to connect devices such as the thermostat or condenser fan at the relay, Fig. 22-13. The system thermostat must be connected in series with one side of the power supply before the power reaches the relay. This permits it to cycle the condensing unit in response to temperature changes. The condenser fan is connected in parallel, *after* the thermostat, so that it can be cycled on and off along with the compressor.

Solenoid-type amperage relay. The solenoid-type amperage relay operates on the principle of excess amperage flow to the motor's *run* winding at start-up. Therefore, the current-sensing device must be connected in series with the run winding.

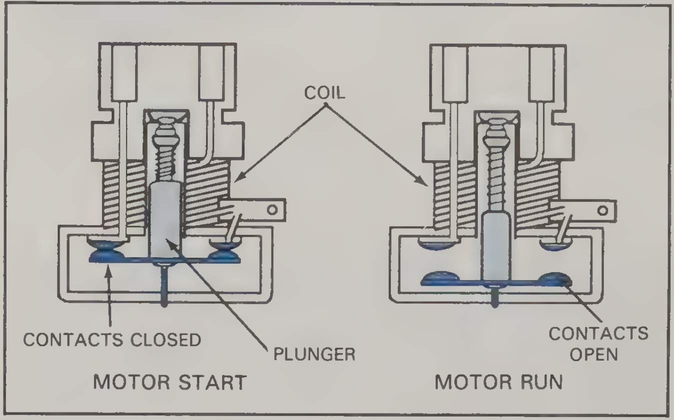


Fig. 22-10. When the coil of the amperage relay is energized, the plunger is pulled upward and closes the contacts to energize the motor's start winding. As motor speed increases, current flow to the coil decreases. The magnetic field weakens, allowing the plunger to drop down, opening the contacts.

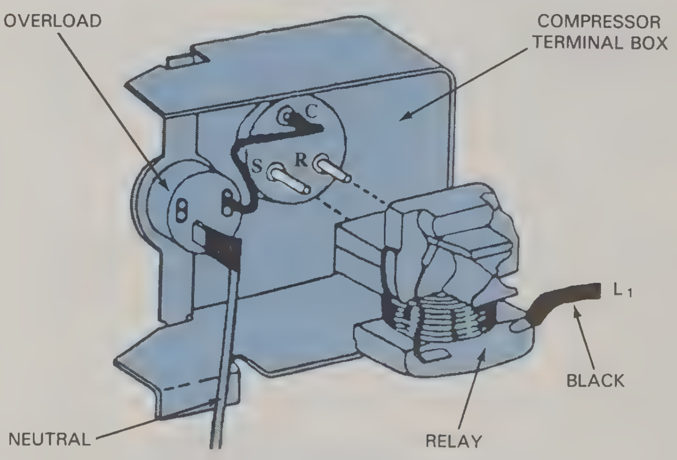


Fig. 22-11. Installation of the amperage relay is simple: it pushes onto the R and S terminals of the compressor. This mounting method helps assure correct positioning.

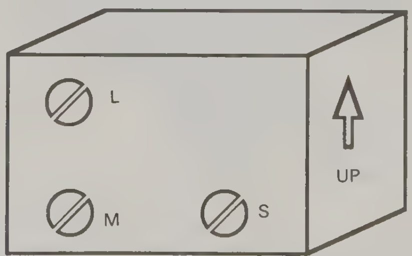


Fig. 22-12. An amperage relay in a plastic case that is not mounted on the compressor. The letters designate terminals.

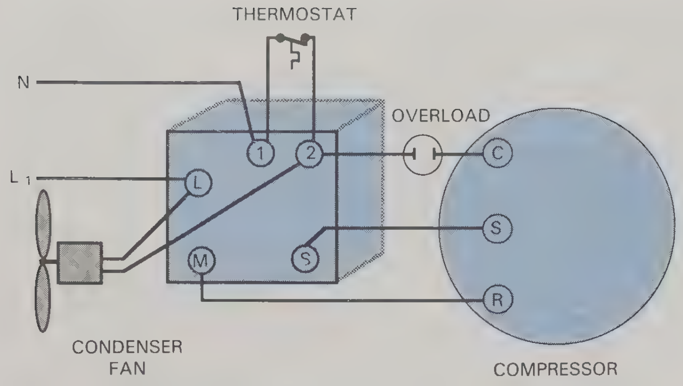


Fig. 22-13. Dummy terminals on the relay case are useful for connecting such devices as the thermostat and the condenser fan.

This sensing device is usually a small coil of heavy gauge copper wire that operates like an electromagnet or solenoid. See Fig. 22-14. The large wire used for the coil will require large amperage flow to create the necessary magnetism to lift the core plunger to close the contacts. When the coil is deenergized, gravity (assisted by a spring) returns the contacts to the open position.

The solenoid-type amperage relay is position-sensitive. It must be mounted both upright *and* right-side-up. If the relay is not upright, the plunger will not be able to rise and fall. If mounted upside-down, the contacts would remain closed because the plunger could not fall back to the open position.

Amperage relay replacement. Fractional horsepower single-phase motors rated at less than 1/2 hp use amperage relays. Single-phase motors with ratings of 1/2 hp and above must use potential-type relays (which differ considerably from amperage relays).

Amperage relays are selected according to motor horsepower; replacement must be exact for proper operation. Manufacturers place an identification number on each relay, so exact replacement is merely a matter

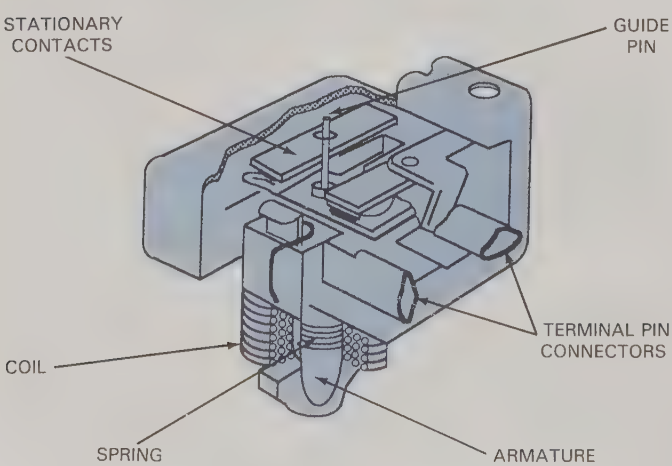


Fig. 22-14. A solenoid-type amperage relay operates in a manner similar to other amperage relays, using high amperage in the run winding to close the contacts.

of specifying the manufacturer's name and the relay identification number. If the number is missing or unreadable, provide the electrical supplier with the model number and serial number of the motor-compressor. A cross-reference listing will allow the supplier to identify the correct replacement relay.

Potential relays

The *potential relay* (also known as the ***voltage relay***) does the same job as an amperage relay, but depends upon the counter-emf (potential) that is generated by the start winding. The speed of the rotor determines the amount of counter-emf generated by the start winding; as speed increases, so does the counter-emf.

Terminals on potential relays are identified by numbers (rather than the letters used on amperage relays). Fig. 22-15 shows the active terminals, which are conventionally labeled as 1, 2, and 5. The contacts are located between terminals 1 and 2; the coil between 2 and 5. This information is important to remember, since not all potential relays show it on the case. Most potential relays have dummy terminals labeled 4 and 6, which are included as a convenience for splicing wires. Use of these terminals to connect a thermostat in series with the run winding is shown in Fig. 22-16.

Some potential relays are position-sensitive; others are not. A relay that *is* position-sensitive will have some indication (usually an upward-pointing arrow) printed on the case. The difference between the two types is in how the movable arm is returned to place the contacts in their normally closed (NC) position. Relays that are not position-sensitive use spring tension to move the arm and re-close the contacts. The position-sensitive types have a weight on the contact end of the arm. When the coil is deenergized, the weight pulls the contacts down to the closed position. The relay must be mounted upright to permit proper closing of the contacts.

Testing relays. When a motor fails to start, the relay, start capacitor, and start winding are checked to identify the source of the problem. Components usually fail in this order:

1. Start capacitor.
2. Relay.
3. Start winding.

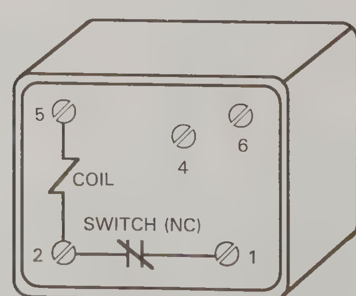


Fig. 22-15. Active terminals on the potential relay are labeled as 1, 2, and 5. Terminals 4 and 6 are dummies that can be used for wire splicing.

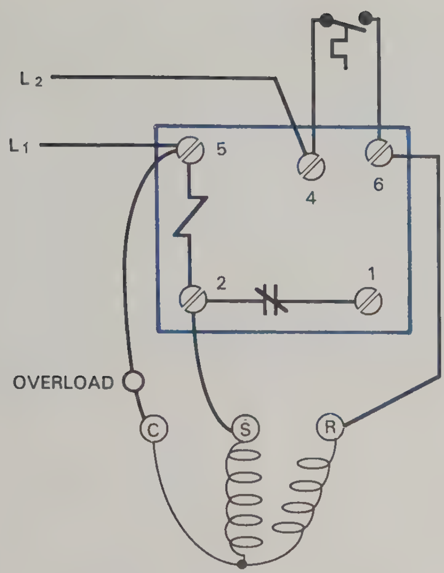


Fig. 22-16. A thermostat is wired in series with the run windings, using dummy terminals 4 and 6 of the potential relay.

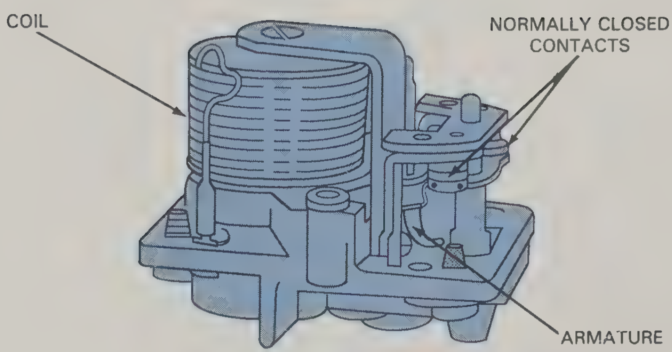


Fig. 22-17. The potential relay's contacts are normally closed. When speed of the motor is fast enough to generate a predetermined amount of counter-emf, the coil is energized. The magnetic field generated by the coil moves the armature, opening the contacts and taking the start windings out of the circuit.

COIL NO.	PICK UP VOLTAGE	DROP OUT VOLTAGE	CONTINUOUS VOLTAGE	COIL OHMS (APPROX.)
1	139-153	15-55	130	760
2	140-153	20-45	170	1400
3	159-172	35-77	256	3320
4	261-290	50-100	336	5180
5	280-310	50-100	395	7150
6	299-327	50-100	420	10000
7	323-352	60-135	495	11950

Fig. 22-18. This table shows the pickup voltage ranges and other information on different relay coils that are available.

Testing of start capacitors and start windings is covered later in this chapter.

The amperage *relay* is checked for proper operation by using an ohmmeter. For safety and proper testing, the relay must be disconnected from the circuit and removed from its mounting. To check the contacts, first hold the relay in the upright position and place the ohmmeter test leads at the M and S terminals. The relay contacts should be *open* in this position, giving a resistance reading of infinity. If a zero resistance reading is obtained, the contacts are welded together, and the relay must be replaced. If an infinity reading was obtained in the upright position, turn the relay upside down. The meter should now read zero resistance, indicating that the contacts have closed. Another means of checking a relay is with the use of a shop-made test cord. This procedure is described under "Troubleshooting," later in this chapter.

To check the relay coil, place the ohmmeter test leads at M and L. A reading that shows a *small* resistance (1 ohm is likely) means that the coil has continuity. If an infinity reading is registered, the coil is open, and the relay should be replaced.

Potential relay operation. The potential relay uses a normally closed (NC) switch that is *opened* by the energizing of the coil. See Fig. 22-17. The contacts control the power supply to the start winding of the motor. Since resistance of the coil is high, it will take a fairly high voltage to overcome resistance and energize it. Coil resistance is precisely measured so that, when the rotor speed reaches 75 percent of normal, counter-emf will be sufficiently high to allow energizing of the coil. This point is called ***pickup voltage.*** Coils are available with pickup voltages in different ranges, as shown in Fig. 22-18.

When the coil is energized, it pulls downward on one end of a pivoted metal arm, or armature. The other end of the armature pushes the electrical contacts open, cutting off current flow to the start winding. The relay coil will hold the contacts open so long as motor speed is high enough to generate sufficient counter-emf.

Terminal connections. Since the potential relay functions on counter-emf generated by the start winding, the coil must be connected to both ends of the start winding. As shown in Fig. 22-19, one end of the coil is connected to the winding at terminal 2, and the other end through the common at terminal 5.

The potential relay is the center of electrical activity, with many devices connected to or through it. These usually include such devices as the overload, system thermostat, condenser fan, and start capacitor. When connecting these devices, you must be correct–electricity does not permit mistakes. When you are making a number of connections, the best course is to consider and connect one wire at a time, double-checking each circuit as you work on it.

Connecting hermetics. There are a number of methods used to make connections to the relay and compressor terminals. If extra terminals are available for multiple

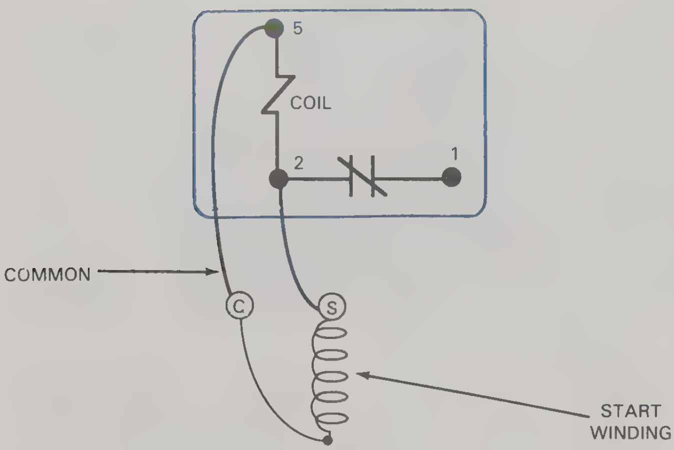


Fig. 22-19. The coil must be connected to both ends of the start winding. It is connected through the common at terminal 5, and (on the other end) at terminal 2.

connections, a fair amount of wire can be saved. No matter what method is used, the basic principles remain the same:

- the power supply is always connected to the common and run terminals.
- the overload is wired in series with common.
- the relay coil is connected to both ends of the start winding.
- the start capacitor is in series with the relay switch.
- the run capacitor must be connected to bypass the relay switch.

Only three terminals (common, start, run) are available on the hermetic compressor itself; most wiring connections must be made on the relay. Fig. 22-20 shows how the power supply is typically connected to common from terminal 5. The counter-emf wire from terminal 5 to common serves a dual purpose. The power supply traveling to common will not interfere with the c-emf circuit. The voltage will not influence the overload, either, since the current flow through the counter-emf circuit is extremely small.

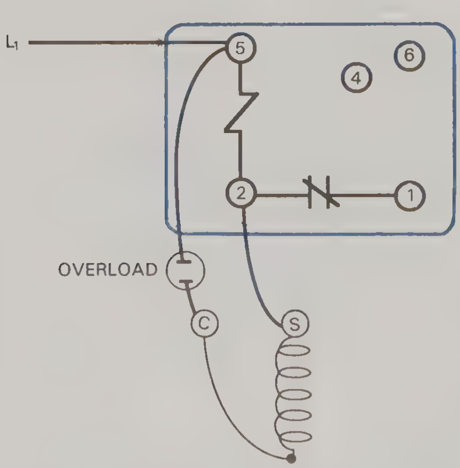


Fig. 22-20. The power supply is wired to common at terminal 5. Note the overload wired in series with common.

The other side of the power supply must be connected to the run winding. This is done through a dummy terminal, terminal 4, to allow connection of the system thermostat in series with the run winding. As shown in Fig. 22-21, the thermostat is connected to terminals 4 and 6. This temperature-activated switch will control power supply to the motor/compressor at run.

If the motor-compressor is a split-phase type (one without capacitors), a ***jumper wire*** must be installed from terminal 6 (power) to terminal 1 (switch) on the relay. See Fig. 22-22. The jumper wire completes the parallel connection from one end of the start winding

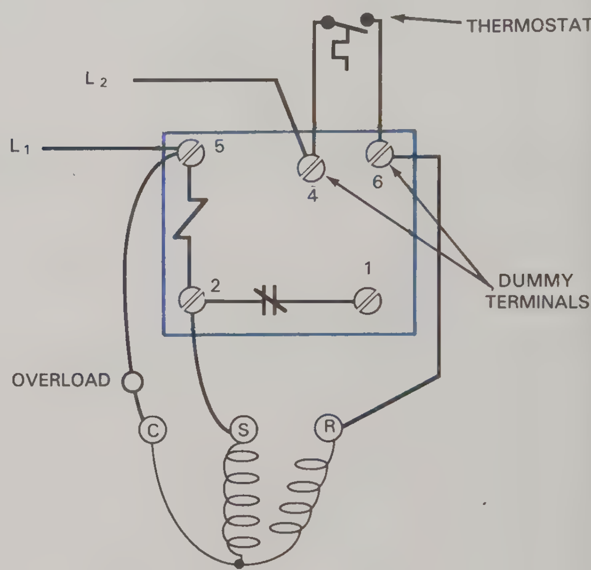


Fig. 22-21. The thermostat is wired in series with the run winding and one side of the power supply, using dummy terminals 4 and 6.

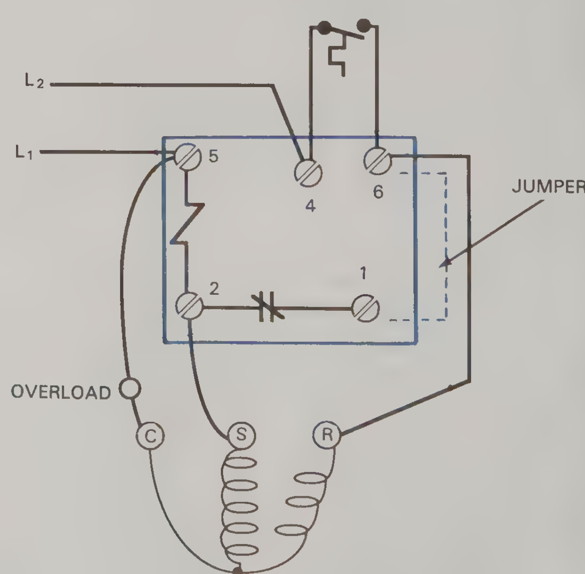


Fig. 22-22. On split-phase motor-compressors, a jumper wire connects terminals 6 and 1 on the relay to provide a parallel connection between the power supply and the relay switch.

to the other side of the power supply; the relay switch is in series with the start winding. The relay switch is closed (NC) at start-up, and will not open until the motor reaches 75 percent of normal speed. When the switch opens, the start winding is disconnected from the power supply. The counter-emf circuit remains intact whether the relay switch is open or closed.

If the hermetic motor-compressor is a *capacitor-start, induction-run (CSIR)* type, the jumper wire is used to install a ***start capacitor*** between terminals 6 and 1, as shown in Fig. 22-23. This places the capacitor in series with the switch, so that both the capacitor and the start winding are disconnected from the power supply when the switch opens.

A *capacitor-start, capacitor-run (CSCR)* motor has a run capacitor wired so that it bypasses the start capacitor and switch. A typical method of wiring the start capacitor into the circuit is shown in Fig. 22-24. When both start and run capacitors are wired as shown, opening of the relay switch will take just the start capacitor out of the circuit. The run capacitor will keep the start winding slightly energized to assist the run winding under loaded conditions.

Condenser fan connections. Since the condenser fan is usually cycled on and off with the compressor, it is wired to the relay as shown in Fig. 22-25. The condenser fan is connected to terminals 5 and 6 (controlled by the thermostat) to achieve this. If the fan were connected to terminals 4 and 5, ahead of the thermostat, it would run continuously.

Connecting semi-hermetics. To prevent possible damage to the actual C, S, and R terminals, most semi-hermetic compressors have a terminal board with dummy terminals. These dummy terminals are connected to the nut-and-bolt type C, S, and R terminals with copper jumper bars. See Fig. 22-26. The overload is normally installed at the factory. The relay and capacitors are housed separately, in a metal box usually called a *power pack*. The wires connecting the terminal

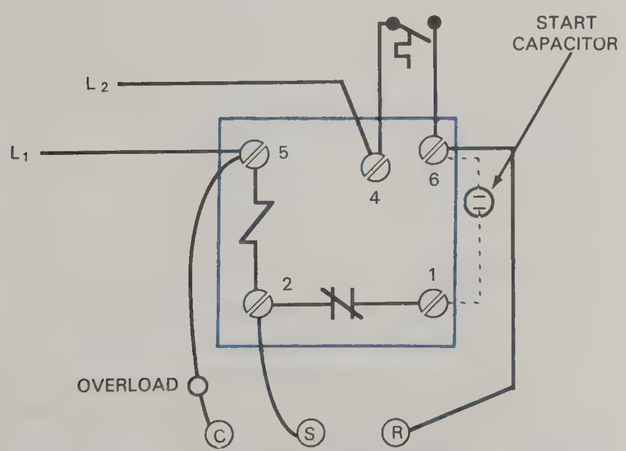


Fig. 22-23. On a CSIR motor-compressor, a start capacitor is connected between terminals 6 and 1 so that it is in series with the relay switch.

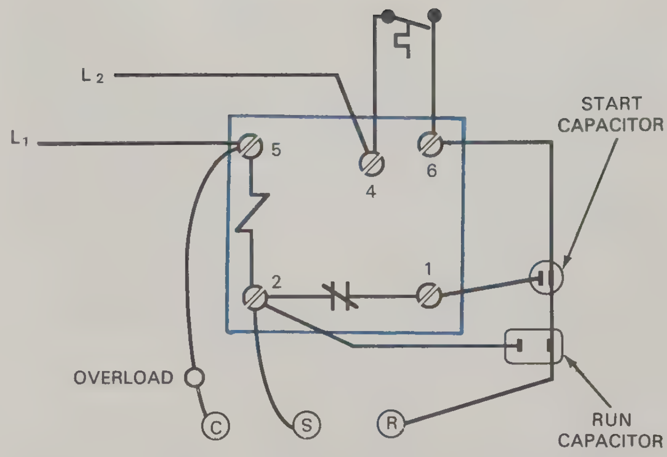


Fig. 22-24. Method used to wire capacitors to the relay. When the relay switch opens, the start capacitor will be taken out of the circuit.

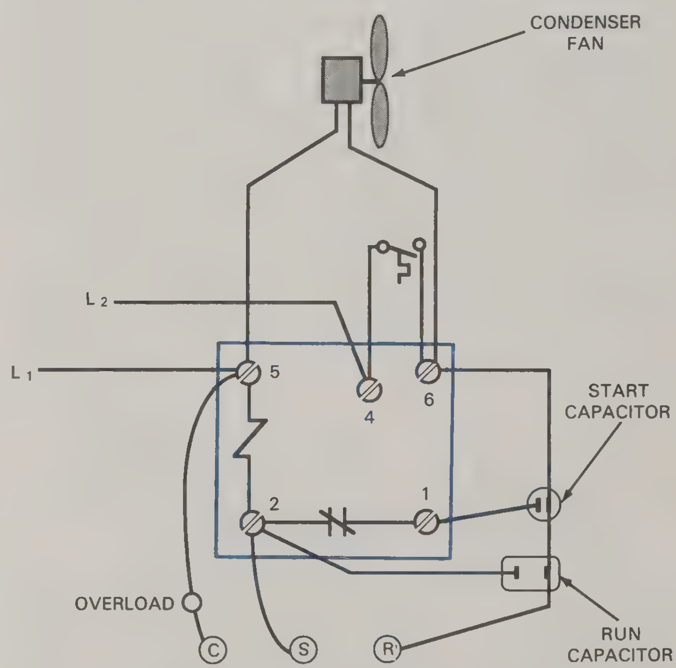


Fig. 22-25. When the condenser fan is wired to terminals 5 and 6, the opening and closing of the thermostat contacts will cycle it on and off along with the compressor.

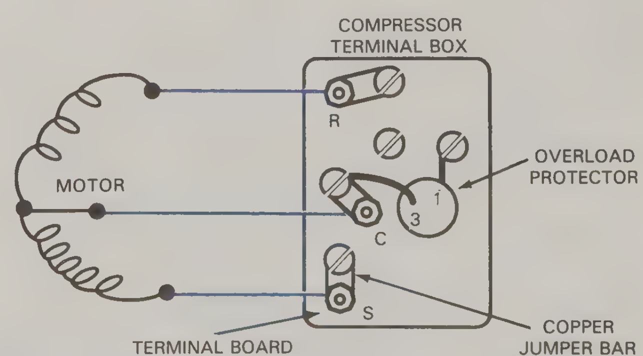


Fig. 22-26. The C, S, and R terminals are connected to dummy terminals with copper jumper bars. The dummy terminals should be used for all connections.

board and power pack are carried in a flexible metal conduit.

Fig. 22-27 shows the usual method for wiring a potential relay and capacitors to the terminal board.

- The overload is in series with Common.
- The relay coil is connected between Common and Start.
- The relay switch and start capacitor are in series with Start.
- The run capacitor is in series with Start, but bypasses the relay switch.
- The system thermostat is in series with one power supply line.
- The condenser fan is connected in parallel with the compressor, *after* the thermostat.

Solid-state relays

Solid-state relays, used primarily in residential air conditioning, are convenient and reliable. They can be used to turn any permanent split capacitor (PSC) motor into a capacitor-start induction-run (CSIR) motor to resolve hard start problems. The ***hard-start kit*** consists of a solid-state relay and a capacitor in a single package. The two terminals on the kit are simply connected in parallel with the run capacitor terminals, Fig. 22-28.

The solid-state relay contains a device called a ***positive temperature coefficient (PTC) ceramic thermistor.*** The thermistor reacts rapidly to temperature change

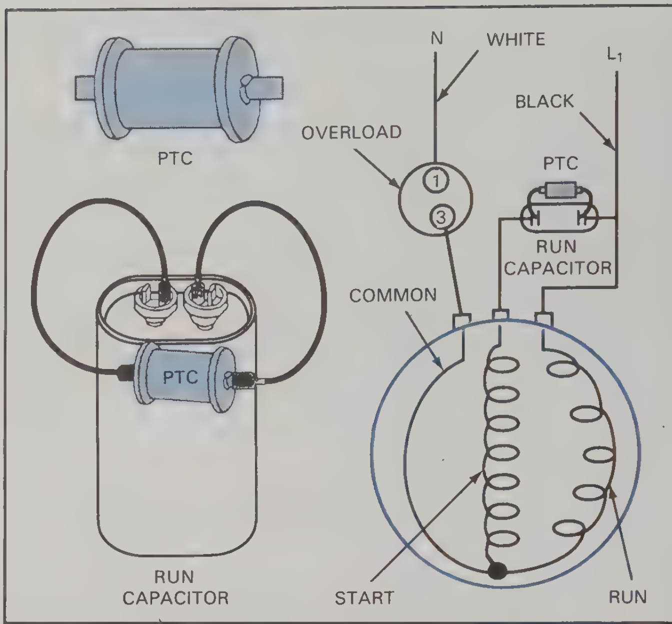


Fig. 22-28. A hard-start kit, wired in parallel with the run capacitor, turns a PSC motor into a CSIR motor to resolve starting problems. A positive temperature coefficient ceramic thermistor in the hard-start relay controls current flow to the windings.

(has a "steep slope") by greatly increasing its resistance to current flow. As used in a hard start kit, this means that the PTC will initially allow the large current flow to the motor's start winding needed for starting. In a period of less than one second, however, heat from that large current flow will cause the PTC resistance to increase from about 50 ohms to approximately 80,000 ohms. This high resistance effectively stops current flow though the relay, allowing normal current flow through the run capacitor and motor winding.

Advantages of the hard start kit (solid-state relay and capacitor) include:

- Low cost.
- Simple two-connection installation.
- Wide applicability (usable on all single-phase PSC compressors up to 340 volts and motors up to 5 hp).
- Reliability and long life.
- Mounting flexibility (not position-sensitive).
- Increased torque (up to 300%).
- Capability of further increasing torque by wiring second kit in parallel to first.

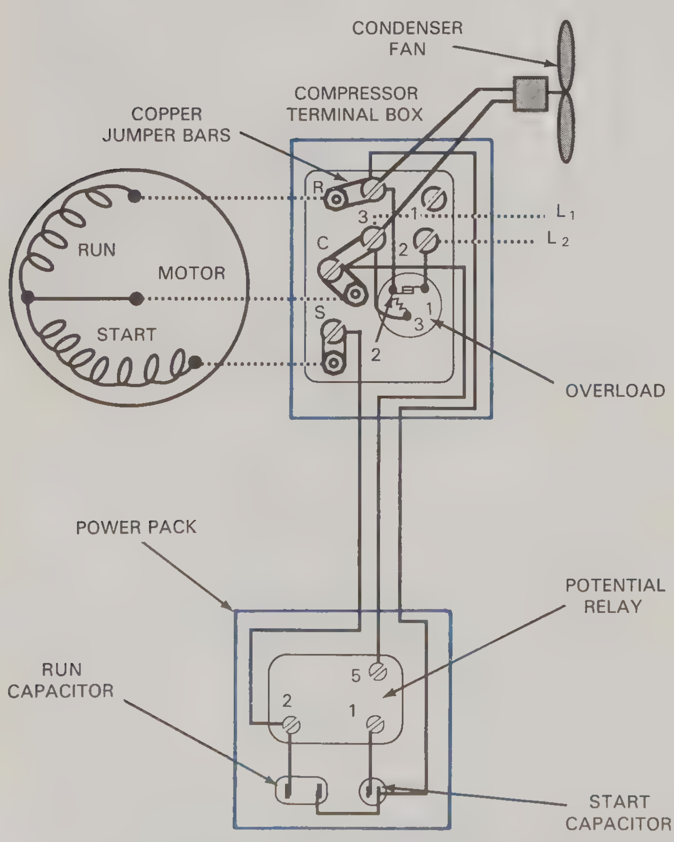


Fig. 22-27. Wiring of potential relay and capacitors to compressor terminal board.

Troubleshooting

If the system is not running, always check the incoming power supply before making other electrical tests. Power supply to a potential relay can be checked by touching the leads of a voltage tester to terminals 4 and 5. If no voltage reading is obtained, check the fuse or breaker for the circuit serving the system. The fuse may be blown or the breaker tripped. If correct voltage is present at terminals 4 and 5, move the test lead from

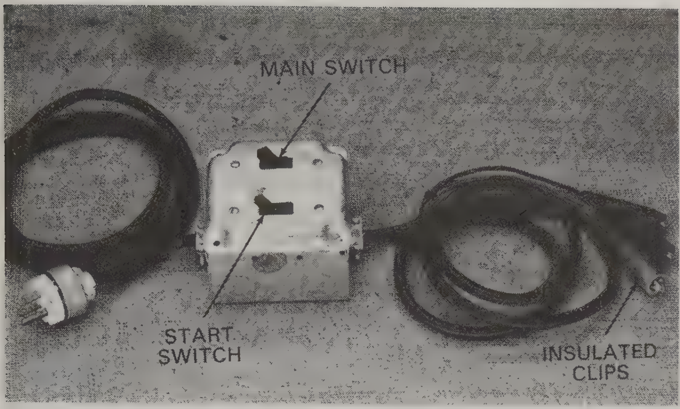


Fig. 22-29. The shop-made test cord is useful for many troubleshooting procedures when servicing hermetic and semi-hermetic units.

terminal 4 to terminal 6. If there is no voltage present at terminals 5 and 6, the system thermostat is open.

Shop-made test cord. A simple test cord with two switches, Fig. 22-29, can be constructed by the technician. This test cord can be used along with a clamp-on ammeter to perform many troubleshooting procedures on small hermetic and semi-hermetic compressors. It is especially useful for bypassing start components and manually operating hermetics. Among other uses, it can also be used to safely check the switch on potential relays. Fig. 22-30 lists the materials and shows the schematic needed to construct the test cord. The test cord can easily be converted to operate on 230V by constructing another length of SJ cord with a 120V female plug on one end and a 230V male plug on the other end. The test cord will operate the same way with either voltage.

WARNING: Exercise extreme care and obey all electrical safety precautions when using this test device, since *it contains no built-in safety devices.* Always connect a safety ground wire to the device being tested. Install a Ground Fault Circuit Interrupter (GFCI) and an additional safety ground wire from the switch box to the device being tested, as well. Illustrations are intended to show principles of use, and do not include recommended safety features.

Manual compressor test-cord start. Turn off both test cord switches and insert the plug into a power receptacle. Disconnect wires from the compressor's C, S, and R terminals and replace them with the test cord clips (white to Common, black to Run, and green to Start). Clamp an ammeter around the wire to Common. To attempt start-up, turn on both test cord switches at the same time to supply power to both the start and run windings. After about one-half second to one second, open the test-cord "start" switch to cut off the power being supplied to the start winding. The motor should continue to run and pull normal amperage.

Use a clamp-on ammeter to observe amperage flow while operating the switches. If necessary, a start capacitor can be easily connected in series with the green clip and the start winding.

Checking potential relays. When the test cord is used to check a potential relay, both switches are placed in the off position and the plug is *not* connected to a power source. The *system* power supply is turned off, as well. As shown in Fig. 22-31, the wire from relay terminal 1 is removed and replaced by the green clip. The black clip is connected to relay terminal 2. The test-cord "start" switch is then closed, providing a circuit from

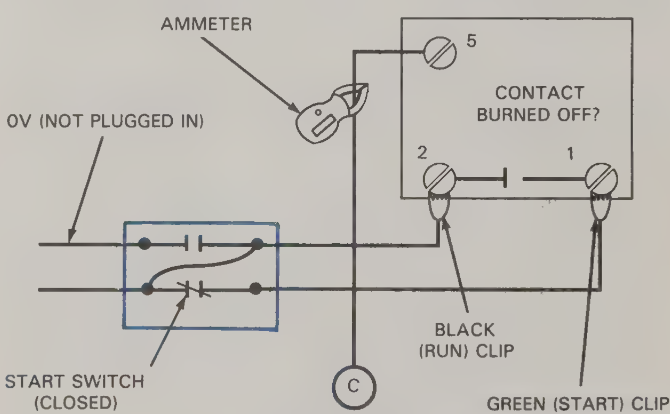
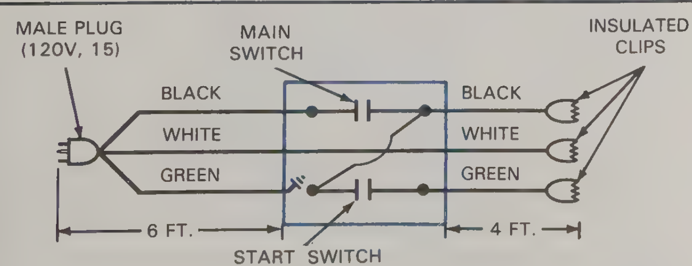


Fig. 22-31. Using the test cord to check the start relay contacts. Closing the ''start'' switch provides a circuit from terminal 1 to terminal 2, with the switch in series between them.



TEST CORD MATERIALS LIST

1	MALE PLUG (120V, 15A)
1	METAL BOX (4'' SQUARE) WITH 1/2'' KNOCKOUTS
1	RAISED BOX COVER WITH DUAL SWITCH OPENINGS
2	SPST 20A TOGGLE-TYPE LIGHT SWITCHES
2	NMC BOX CONNECTORS (1/2'')
3	BULLDOG OR ALLIGATOR CLIPS (WITH RUBBER INSULATING COVERS)
10'	THREE STRAND, 14 GA. SJ CORD

Fig. 22-30. Wiring connections must follow the schematic diagram shown above. Label all switches and clips to prevent confusion. If desired, components of different colors (such as brown and ivory) can be used for the *main* and *start* toggle switches. Power supply to the box is controlled by the *main* switch; the *start* switch controls power supply to the green wire attached to a bulldog clip. The green wire is used for the start winding connection. It becomes a power supply wire only when *both* switches are closed.

the "start" clip to the "run" clip, with the switch in series between them. A clamp-on ammeter is then placed around the wire to Common for observing amperage flow during the start-up procedure.

Observe the ammeter while turning on the *system* power supply and (after about one second), moving the test-cord start switch to the off position. If the compressor starts and runs properly, the relay is defective and should be replaced.

An alternate test method uses just an *ammeter* when troubleshooting problems with solid-state relays. The meter is clamped around one of the wires connecting the relay to the run capacitor and used to read amperage (current) flow. At start-up, the amperage should be high, then quickly drop to normal operating level as the PTC opens the relay contacts and disconnects the start winding. If there is no amperage flow through the relay, or if the amperage does not drop (indicating that the relay contacts have not opened), the relay is defective and should be replaced.

Faulty run capacitor. If the motor-compressor starts okay and runs for a short time, then shuts off on the overload, the run capacitor should be suspected. The run capacitor seldom proves faulty, however, and high head pressure can cause the same symptoms. Install a gauge manifold and check for high head pressure before checking the run capacitor.

If the relay checks out properly, but the compressor fails to start, the problem is in the *compressor*. It may have a faulty start winding, or may be physically binding ("locked up").

Open start winding. The start winding may be open, and can be checked for continuity with an ohmmeter. A reading of infinite resistance will be obtained if the circuit is open. **Caution:** To protect the meter from damage, all power to the circuit being tested *must* be off. For safety, remove all wires to the compressor terminals before testing for continuity.

Starting a locked-up hermetic. Sometimes a hermetic or semi-hermetic will not start when the start components and motor windings prove okay. This condition indicates a mechanical problem in the compressor: a bearing may have seized or a small piece of solder may have become wedged between the piston and cylinder wall. Sometimes the unit can be restarted. The effort is worth the trouble if successful; if not, the unit must be replaced.

There are three methods commonly used to try breaking loose a locked-up compressor. **Caution:** These methods are to be tried only briefly (about one second) to avoid possible electrical damage to the system.

- **Reversing rotation** by switching the wires from the start and run windings. This reverses the magnetic field and makes the motor run backward. A high-capacity start capacitor (rated at 400-500 mfd) should be connected in series with the new start winding (actually the run winding). For a stuck *three-phase compressor,* reverse rotation by exchanging connections of any two supply voltage wires. It makes no difference which two wires are changed; the magnetic fields are automatically reversed.
- Using a **high-capacity start capacitor** (400-500 mfd) will create a very strong magnetic field in the start winding. This method does not reverse rotation, but greatly increases starting torque.
- **Using higher voltage** to increase starting torque. If the stuck motor-compressor is 115 volts, install a high capacity start capacitor, then apply 230 volts to the compressor terminals. Reversing rotation can be combined with the higher voltage, as well.

If the procedure is successful and the compressor restarts, reconnect all wiring to its original terminals. Remove the extra capacitor.

It is not always possible to successfully start a locked-up compressor, and *if* re-started, there is no guarantee the compressor will not become stuck again. (Sometimes, a restarted compressor runs for years; then again, it may lock up once more in just a day or two.) Always advise the customer that this procedure is worth trying, but may not succceed or "stay fixed." This can avoid trouble and any argument regarding a "recall." The customer may choose not to gamble and authorize immediate compressor replacement.

Cycling on the overload. It is quite possible for the motor-compressor to be *cycling on the overload* while the condenser fan is operating. This condition is marked by operation of the overload each time the motor attempts to start (resulting in a "hmmmmm...click, hmmmmm...click" sound pattern). This provides several items of information:

- The overload is doing its job of protecting the compressor from damage.
- The power supply is adequate and the thermostat is closed, or the fan would not be running.

If the head pressure is normal, the problem is in the start components or the compressor motor windings.

To pinpoint the problem's location, use a clamp-on ammeter to check each circuit connected from the relay to the compressor. The *order* in which checks are performed is a matter of experience and the component locations.

Motor shorted to ground. This is difficult to check, because there is an extremely short period in which to measure current flow before the overload contacts reopen. Clamp the ammeter around either the run or common wire from the relay to the compressor, and wait for the overload to cool. When the overload contacts close, the extreme current flow caused by the short will generate sufficient heat to reopen them almost instantly.

The amperage reading, if you can obtain one, will be very high (as much as six times the current flow for normal operation of the motor). This indicates that the motor windings are shorted to ground. Use an ohmme-

ter to check the windings and conform the diagnosis. If there is a short-to-ground (ground fault) situation, the motor-compressor must be replaced.

Making bench tests. The test cord described earlier in this section can be used for bench testing many electrical devices for proper operation. The test cord is used to supply power to the device for the test. For use in bench testing, both test cord switches are turned off and the plug is connected to a power receptacle. The Common and Run clips are attached to the device being tested. An ammeter is then clamped around either wire to permit the technician to observe the amperage flow during start-up. See Fig. 22-32. For safety, connect a ground wire to the device being tested.

While observing the ammeter, close only the "main" switch on the box. This procedure supplies power to the device being tested. If the device is defective, the switch can be quickly turned off.

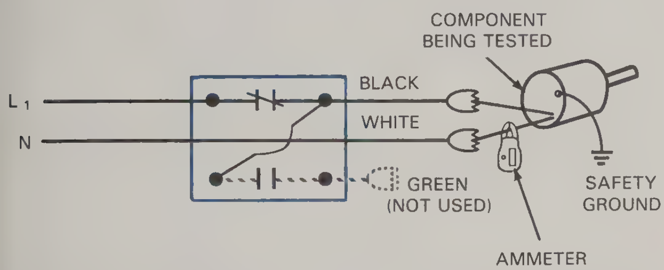


Fig. 22-32. Using the test cord for bench-testing an electrical component. The cord provides a 120V (or 230V, with adapter cord) power supply.

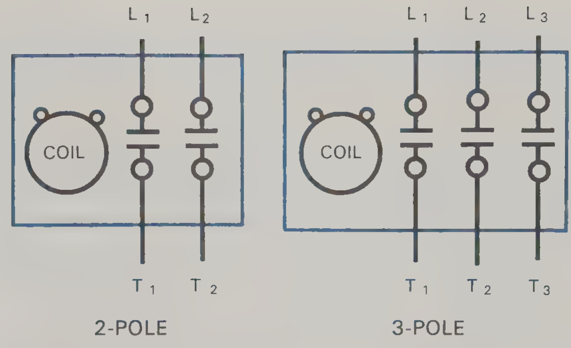


Fig. 22-33. Schematic views of 2-pole and 3-pole contactors.

CONTACTORS

A ***contactor*** is an electromagnet used to control multiple *heavy duty* contacts that are opened or closed at the same time. The contacts are normally open, and close when the relay coil is energized. A 2-pole contactor has two separate contacts and a 3-pole contactor has three contacts. (A three-phase motor uses a 3-pole contactor to simultaneously control all three hot legs.) See Fig. 22-33. The major difference between a relay and a contactor is the size of the contacts. Contactors are used to control power to large loads. Higher amperage flow to large loads requires the use of heavy duty contacts. Some typical contactors are shown in Fig. 22-34.

A movable armature (insulated bar) is located close to the iron core. This armature carries the movable contacts, which are held away from the stationary contacts

A

B

Fig. 22-34. Typical contactors. A–A 2-pole contactor. (White-Rogers) B–A 3-pole contactor. (Furnas Electric Co.)

by means of a spring. See Fig. 22-35. When the coil is energized, magnetism overcomes the spring pressure, snapping the contacts into the closed position. These Snap-action contacts are used because the contacts must open and close very quickly to reduce electrical arcing that always occurs under load conditions.

These devices are rated according to the maximum amperage flow through the contacts for a specific voltage. The amperage rating is usually expressed in Full Load Amps (FLA), which is an inductive load rating. The same contactor will tolerate a higher amperage if the load is resistive. Specific ratings are listed on the contactor data plate. An oversized contactor is perfectly acceptable; an undersized contactor will result in burned-out contacts.

As a result of arcing when the contacts open and close, it is normal for them to be pitted and burned. Use of a file or sandpaper to clean the contacts is not recommended, since such "cleaning" destroys the contact surfaces and increases arcing. Replacement contacts are usually available from a local supplier.

The numbering system for contactors determines direction of current flow through the contacts. The line power (inlet) terminals are labeled L_1, L_2, and L_3 and the load (outlet) terminals are labeled T_1, T_2, and T_3. Power supply is connected to L_1, L_2, and L_3 and a three-phase motor is connected to T_1, T_2, and T_3. See Fig. 22-36.

Residential air conditioning contactors

Residential air conditioning uses a 230V, single phase circuit to operate the outdoor condensing unit. Power supply is obtained from the main load center (breaker panel) and is connected to the outdoor unit at the 2-pole (L_1 and L_2) contactor. The compressor and the condenser fan are both connected to T_1 and T_2 of the contactor. See Fig. 22-37.

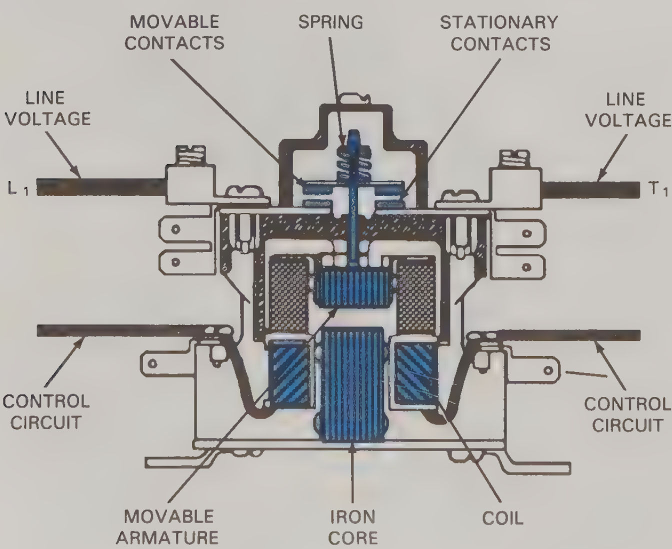


Fig. 22-35. Cutaway view of a contactor. Spring pressure holds contacts apart until the coil is energized and snaps them closed.

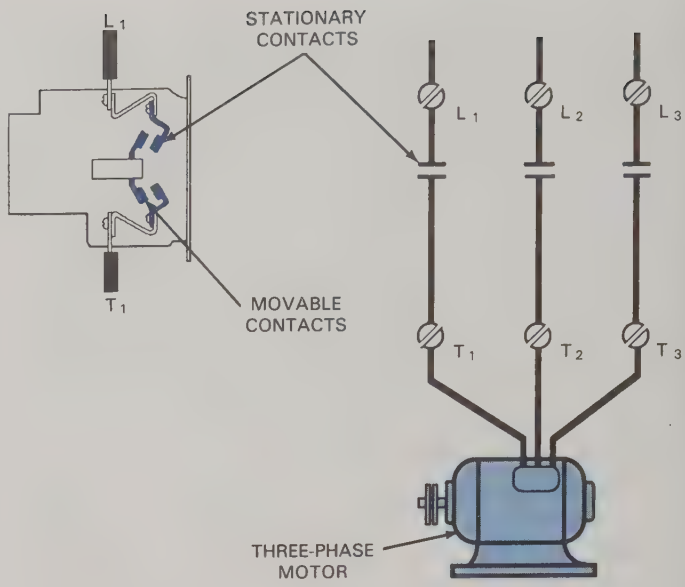


Fig. 22-36. Contactor terminals are labeled with "L" for the line power side and "T" for the load side, where the device is connected. All contacts open and close at the same time.

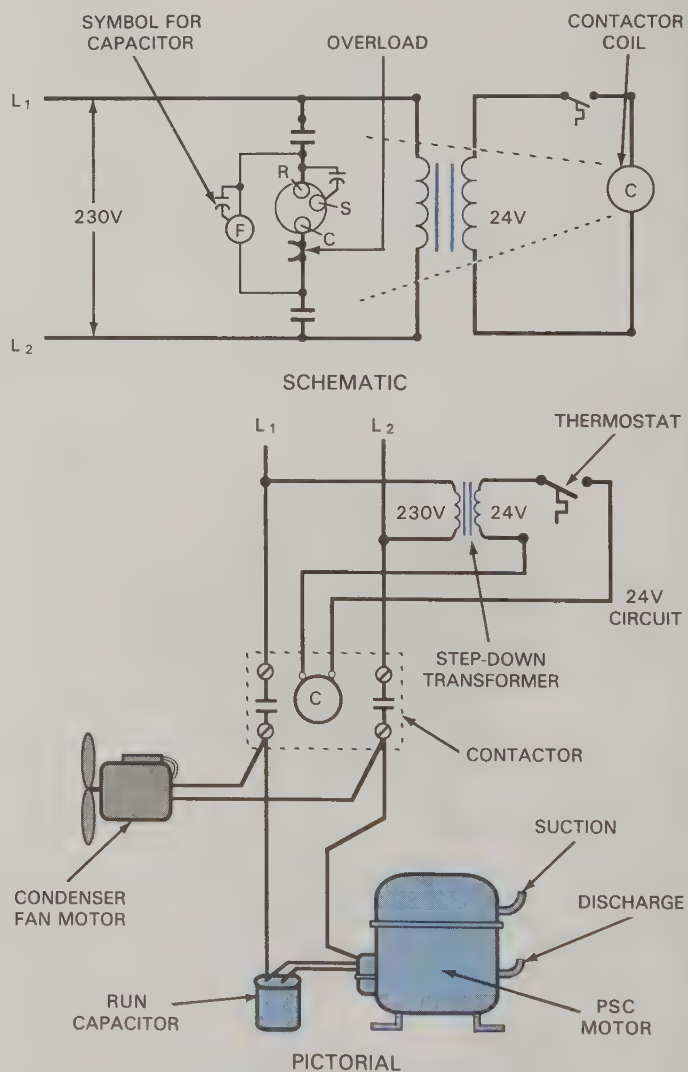


Fig. 22-37. Typical wiring for a residential system, using a two-pole contactor.

The contactor coil and thermostat operate on 24 volts, so a transformer must be used to provide this low control voltage. The low voltage permits the use of very small (18 gauge) wire to connect the indoor thermostat to the outdoor condensing unit.

Commercial air conditioning contactors

Most commercial refrigeration systems operated on 208V or 230V three-phase power systems, but large systems may use 440V. Control circuit voltage is usually 120V, since this allows use of standard switching devices and wiring. See Fig. 22-38. Safety switches and thermostats are connected in series with the 120V control circuit that supplies power to the contactor coil. If the thermostat or a safety switch opens, the contactor coil is deenergized, opening the main contacts and cutting off the power supply to the motor-compressor.

Commercial refrigeration systems also may use a 230V, single phase control circuit. Power supply for the control circuit is obtained from any two supply wires connected to the contactor at L_1, L_2, and L_3. See Fig. 22-39. The two control circuit wires sometimes equipped with fuses to protect the control circuit wiring and the contactor coil. A blown fuse can narrow a problem down to the control circuit.

Contactor coils

The electromagnetic coil is located inside the contactor, but is *not* electrically connected to the main contacts. Because the coil is a separate device, the coil voltage is often different from the voltage at the main contacts. The coil has its own terminals for making electrical connections. Most contactors are designed to allow easy replacement of the coil. See Fig. 22-40.

The coil is used to control the main contacts. Energizing the coil causes the main contacts to close simultaneously. Deenergizing the coil causes the main contacts to open. Power supply to the coil can be controlled automatically or manually. As noted earlier in this chapter, the separate electrical circuit to the coil is called the control circuit. See Fig. 22-41.

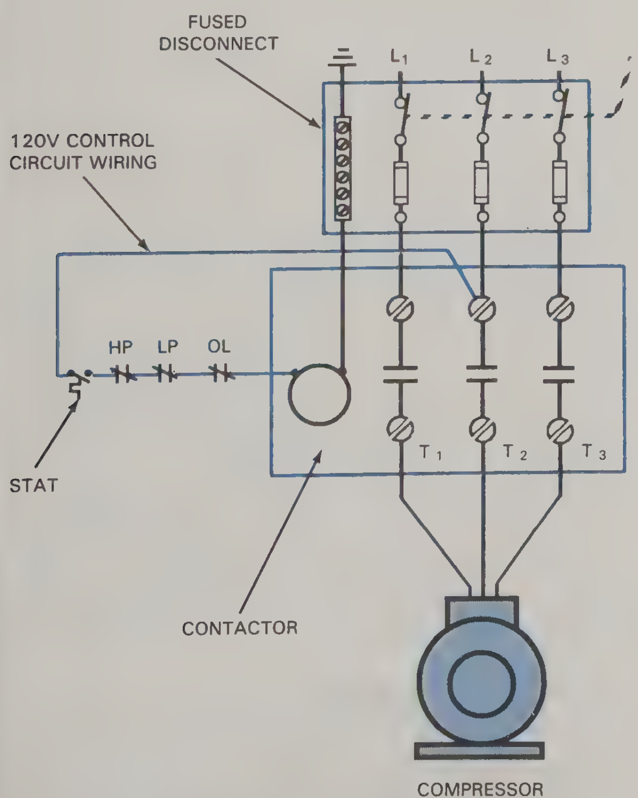


Fig. 22-38. A 230V, three-phase system with a 120V control circuit used for the contactor.

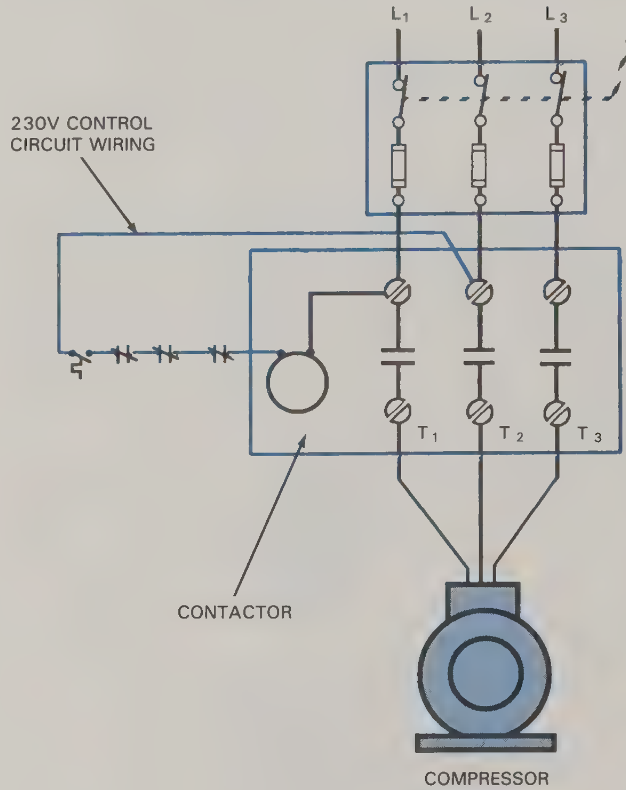


Fig. 22-39. Commercial refrigeration system using a 230V, single-phase control circuit.

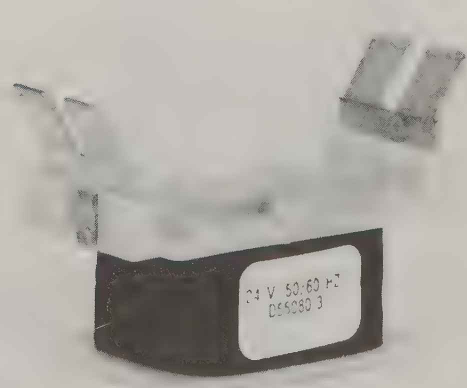


Fig. 22-40. A replacement coil for a contactor. Note the terminals used with push-on connectors for ease of replacement. (Furnas Electric Co.)

Because the coil is electrically separate from the main contacts, it is common practice to use lower voltage to operate the coil. This permits easy control of a large motor operating on high voltage and amperage. Lower voltage and current in the control circuit is safer and permits the use of standard switching devices. As shown in Fig. 22-42, a step-down transformer is used to obtain the lower control circuit voltage.

Any number of contacts and safety control switches can be located in the control circuit, Fig. 22-43. The contacts for these controls are connected in series with the coil and may include overloads, thermostats, pressure controls, fuses, limit switches, flow controls, or other devices. Before the coil can be energized, *all* switches in the control circuit must be closed . Opening *any* switch will disconnect power supply to the coil and stop operation of the motor.

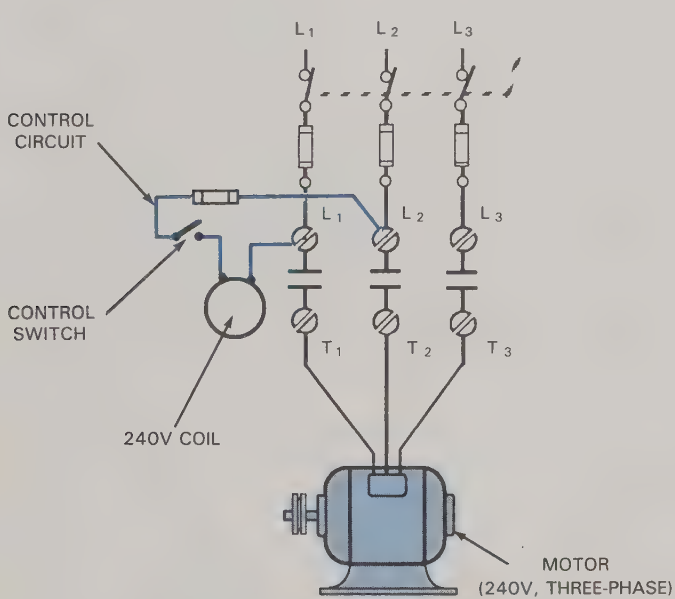


Fig. 22-41. Power supply to the contactor coil can be controlled manually or automatically.

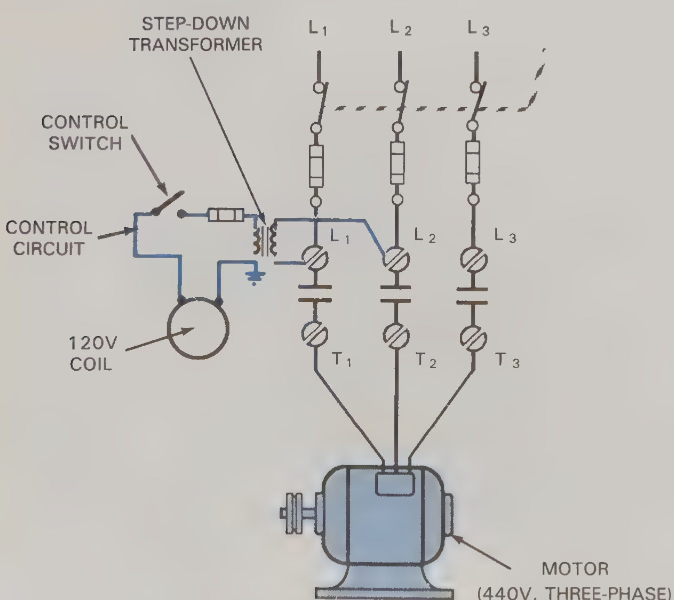


Fig. 22-42. A step-down transformer is used to obtain the lower voltage used for the control circuit.

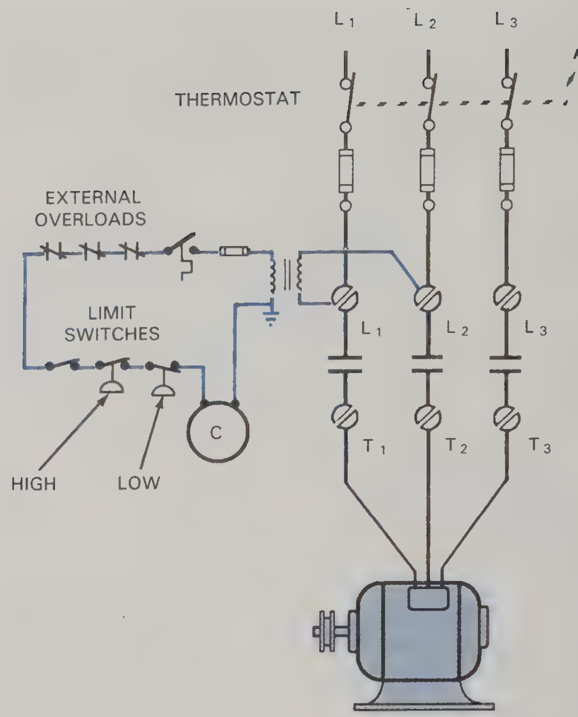


Fig. 22-43. All safety switches and overloads connected to a control circuit must be closed to energize the contactor coil.

WARNING: Although a step-down transformer is often used, control circuit voltage may be obtained from a *separate* power source. Thus, turning off the motor's fused disconnect may *not* deenergize the control circuit. This situation is not unusual and can be dangerous. Never work on a circuit until you are certain the circuit is dead, and cannot be accidentally reenergized while repairs are being made. *Always* check the circuit with your voltage tester before and after deenergizing it. Also, periodically check your voltage tester on a known "live" circuit to be certain it is working properly.

The main switch (***disconnect***) must be properly tagged to inform others that work is being performed on the circuit. ***Lockout***, the physical locking of the switch in the off position, is a safety requirement in most industrial settings. For your own protection, you should make it your *standard procedure* whenever you work on a system. Proper tagout and lockout procedures are important and prevent many injuries and deaths.

Troubleshooting contactors

If the control circuit is not fused (and some are not), the entire system must be checked to locate electrical problems. A voltage tester provides a quick method of locating these problems. With the power supply turned on, check for voltage at L_1, L_2, and L_3 of the contactor.

If the tester shows no voltage at these terminals, the main power source is off. If one or two legs are hot and one is dead, one or more main fuses has blown.

If power supply to the contactor is okay, check for proper voltage at T_1, T_2, and T_3. If one of these terminals is dead and the others are okay, the corresponding contact inside the contactor is burned out.

Control circuit problems. If power supply to the contactor is okay, but no voltage is available at T_1, T_2, T_3 of the contactor, the problem is in the control circuit. Check for voltage at the coil. The coil may be burned out, or a control circuit switch is open, so that the coil is not energized.

To check the contactor coil, test for voltage at the coil terminals. If the voltage is correct, the coil itself is defective and must be replaced. If voltage is not present at the coil, one of the control circuit contacts is open. All switches must be checked to determine which one is open.

Each switch serves a definite purpose for controlling power supply to the coil. Some of these controls are automatic reset; others are manual reset. When the open switch is located, that control pinpoints the problem to be corrected.

Voltage test method. A voltage tester can be used to quickly and easily test switches to determine whether they are open. Electricity will always seek the path of least resistance, so current will not flow through the tester when it can take a lower-resistance path straight through a fuse or closed switch.

As shown in Fig. 22-44, a zero voltage reading (0V) is obtained across a closed switch. Since an open switch or fuse has *infinite* resistance, electricity will flow through the lower resistance of the meter and provide a reading (230V in this case).

Coil voltage too low. Low coil voltage will reduce magnetic pull, so that the armature will not seat properly. This causes excess current, due to loss of counter-emf, so that the coil gets very hot and burns out. "Chattering" of the armature may indicate a low coil voltage condition.

AC hum. All devices using a magnetic field will produce a characteristic hum. This hum is caused by the changing magnetic fields, which produce mechanical vibrations. In addition to hum, noisy operation of contactors, relays, and line starters may be caused by:

- Low voltage.
- Dirt, rust, or metal filings on magnet faces.
- Inability of the armature to seat properly.
- Binding of moving parts.

ACROSS-THE-LINE STARTERS

An across-the-line motor starter, or ***line starter***, is a contactor that has built-in overload protectors. Also referred to as a *magnetic starter,* it is used to operate and protect three-phase motors. Such motors are frequently chosen for belt-driven applications, such as operating compressors, large condensers, exhaust fans, cooling towers, or large air conditioning blowers. The built-in overloads protect the motor against excess amperage (current flow). See Fig. 22-45.

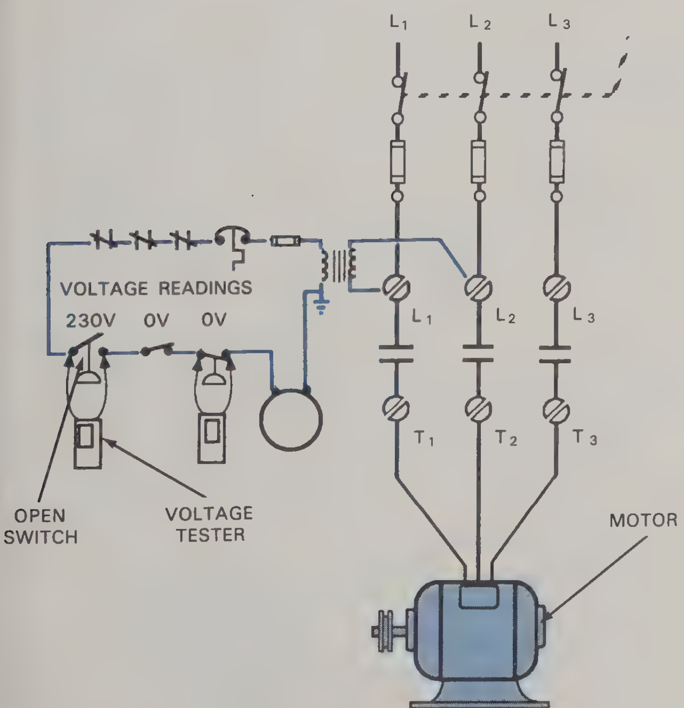


Fig. 22-44. A voltage tester can locate an open switch or fuse by showing the voltage across the switch. A closed switch will register 0V.

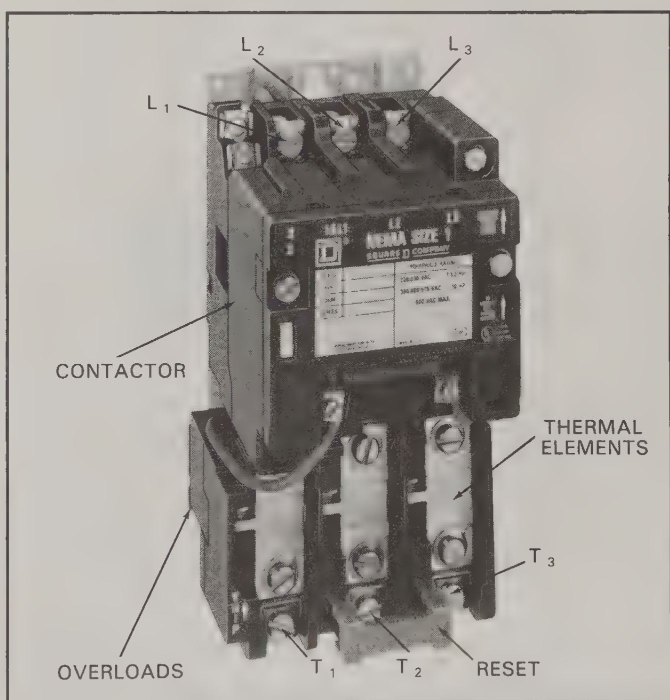


Fig. 22-45. A typical line starter. Most line starters have overload protectors mounted just below the contactor. (Square D Co.)

The overload protectors are normally mounted just below the contactor, and are often installed and prewired at the factory. Overloads are more accurate than fuses, providing excellent motor protection. One overload is needed to protect each phase supplying power to the motor.

The overloads operate on a *thermal* principle, with an element that is sized to permit a specific amperage flow. Excess amperage will cause the element to become hot and operate a trip mechanism that opens a set of contacts. This cuts off the power supply to the contactor coil and stops the motor. See Fig. 22-46. A manual reset is provided to re-close the overload contacts after the thermal element cools off. Thermal elements (sometimes referred to as "heaters") are available in different amperage capacities. They are sized to provide accurate motor protection at slightly above the contactor's Full Load Amps (FLA) rating. See Fig. 22-47.

Each of the three overload contacts is connected in the control circuit. As shown in Fig. 22-48, the factory connects a wire from L_1, through each overload switch to one terminal on the contactor coil. Field wiring of the control circuit is completed by connecting the other side of the coil through the various control circuit switches and back to either L_2 or L_3. This places the thermostat and all overload switches in series with the coil.

Some older line starters are equipped with just two overloads, instead of three. They are based on the principle that if any one supply wire becomes overloaded, another will also be overloaded. Thus, only two overloads are needed to protect the motor. Current electrical codes, however, require three overloads for a three-phase motor. Newer line starters use three thermal elements, but only *one* set of contacts. Any thermal element can open the contact. A manual reset button is used to re-close them. See Fig. 22-49.

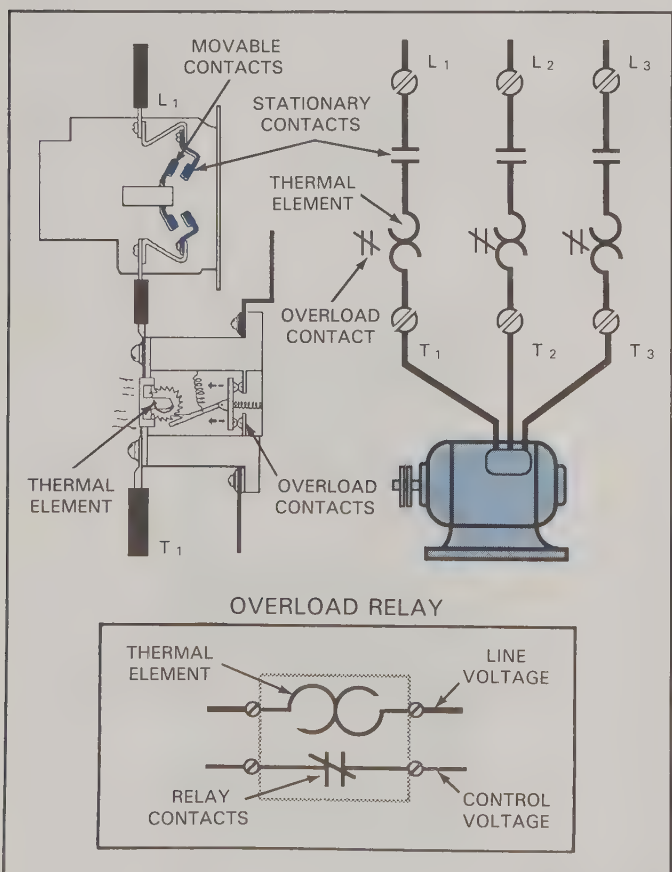


Fig. 22-46. The line starter provides thermal overload protection. Excess amperage will cause the thermal element to become hot and open the overload contacts. This cuts off power to the contactor coil, opening the contacts and stopping the motor.

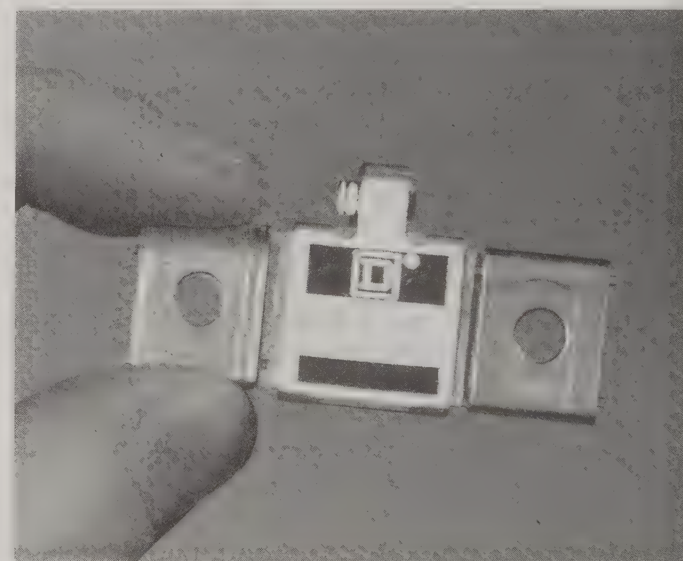


Fig. 22-47. A typical replaceable thermal element. (Square D Co.)

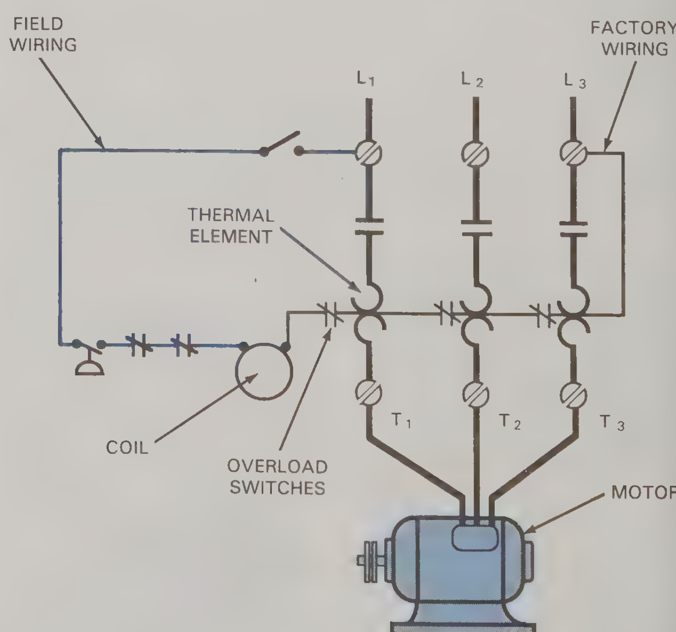


Fig. 22-48. Wiring of the overload switches is usually completed in the field by incorporating the desired control devices in the circuit.

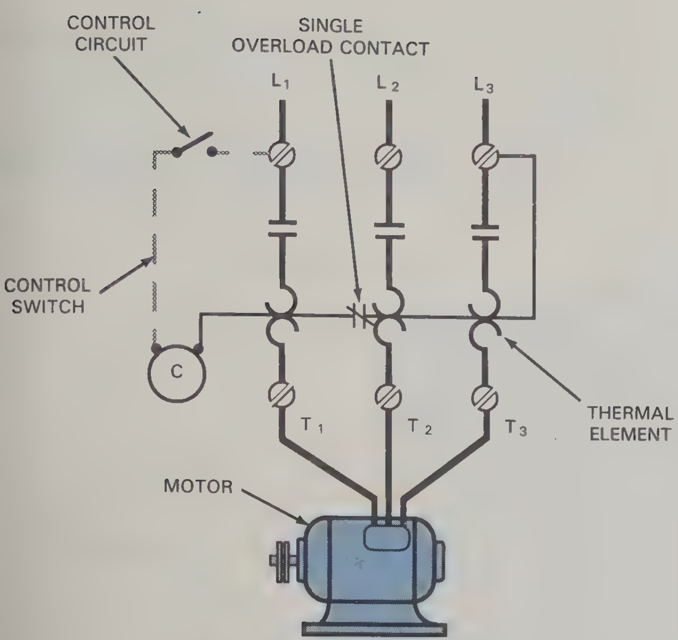


Fig. 22-49. Newer line starters may have three thermal elements, but only a single set of overload contacts. Any thermal element can operate the contacts if an overcurrent problem occurs.

Troubleshooting line starters

Troubleshooting line starters is performed as described under contactors. The only difference is the overloads. If an overload switch opens, power supply to the coil stops and the motor stops. When the overload cools, the reset button is manually pushed to reset the contacts to the closed position and thus restore power to the coil.

WARNING: Pressing the reset button with the control circuit energized will start the motor immediately, while your hand is inside the starter box. *Always* deenergize the control circuit before you press a reset.

The thermal elements and overload switches are very reliable and rarely fail. If the overload will not reset, or quickly opens again, the problem is due to excess amperage. This indicates a motor problem.

Motor control circuits

Some advanced motor control circuits can become quite complex, including relays, lights, pushbuttons, and safety controls. Fig. 22-50 is an example of this type of control circuit, which allows the motor to be controlled from separate locations.

PICTORIAL AND SCHEMATIC DIAGRAMS

Pictorial and schematic diagrams are two different types of illustrations commonly used to show electrical connections. Most manufacturers locate these important diagrams on the inside of a cover panel on the appliance or other equipment. When making repairs and locating system problems, the technician must frequently refer to these diagrams to identify certain wires and component connections.

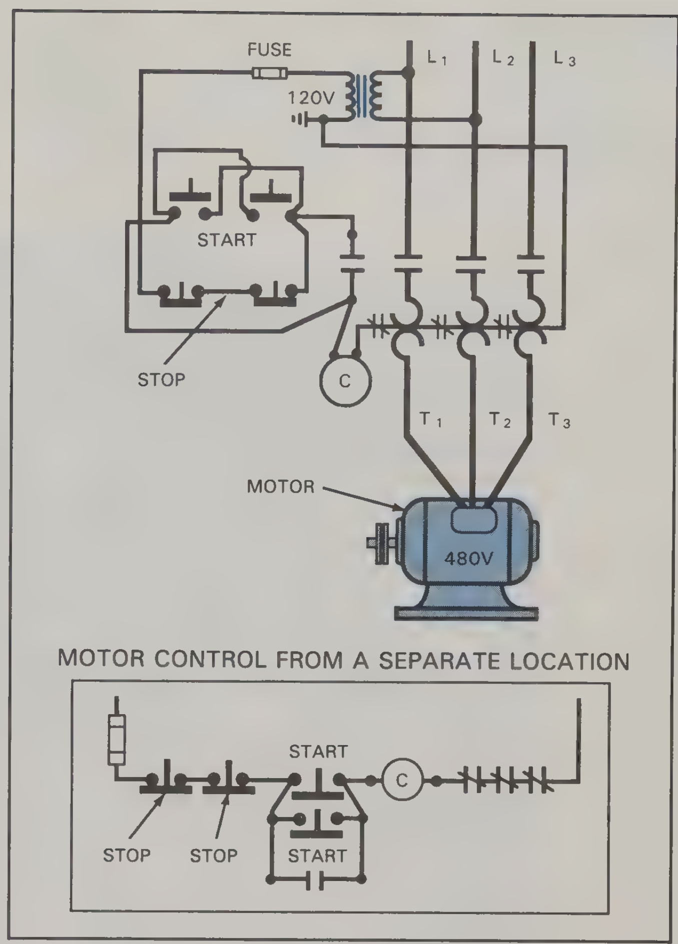


Fig. 22-50. With a more complex control circuit, a motor can be started and stopped from two or more locations. The circuit shown has two pushbutton control switches.

PICTORIAL DIAGRAM

A *pictorial diagram* shows the physical appearance, component locations, wiring connections, and internal arrangement of a piece of equipment. See Fig. 22-51. The components are arranged in the approximate positions they actually occupy inside the unit. Lines are then drawn from each component to indicate how the wires are connected in the circuit. These lines are sometimes labeled with the color or identification number of the wire used.

When many electrical components are involved, the pictorial diagram becomes too difficult to read. There are so many wires in the diagram that it is difficult to follow a single one. To solve this problem, the schematic diagram is used.

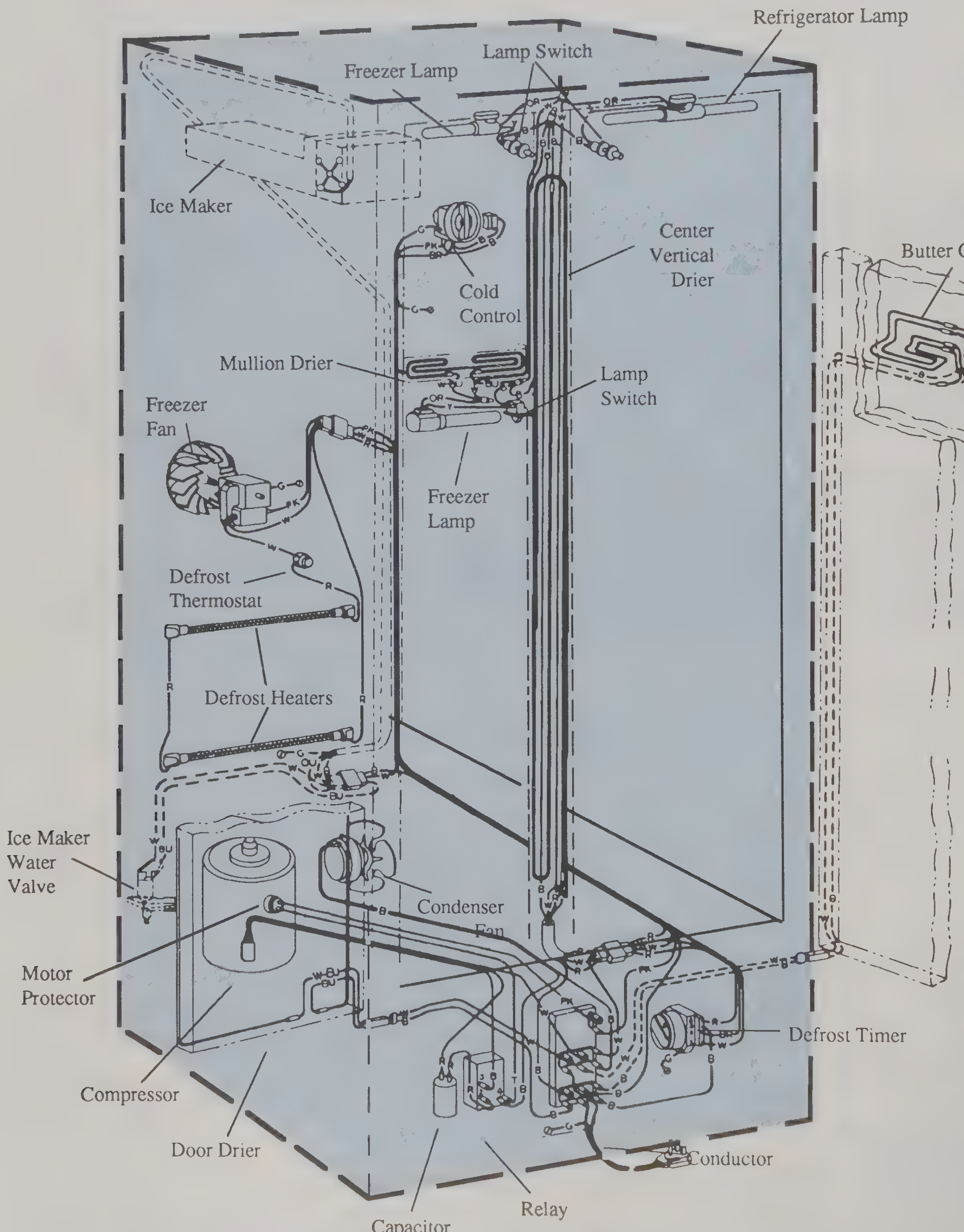
SCHEMATIC DIAGRAM

The *schematic diagram* (usually referred to by technicians as simply the "schematic") is an orderly method of presenting electrical circuits and components. The schematic does not illustrate where the components are

located or what they look like, but the types of components involved and how they are connected in the circuit.

A standard set of ***electrical symbols***, Fig. 22-52, is used for ease of communication in schematic diagrams. There are literally hundreds of different symbols used in electrical and electronic schematics, but technicians quickly learn to recognize those that are most commonly used.

The schematic diagram is often called a ***ladder diagram,*** because it is shaped somewhat like a ladder. The



COLOR	SYM
BLACK	B
WHITE	W
RED	R
YELLOW	Y
GREEN	G
TAN	T
BROWN	BR
BLUE	BU
GRAY	GY
ORANGE	OR
PINK	PK

Fig. 22-51. A pictorial diagram of the type commonly used for household appliances and similar types of equipment. Components are drawn realistically and are shown in the approximate position they occupy inside the case. Note the key for wire colors at lower right. (Frigidaire)

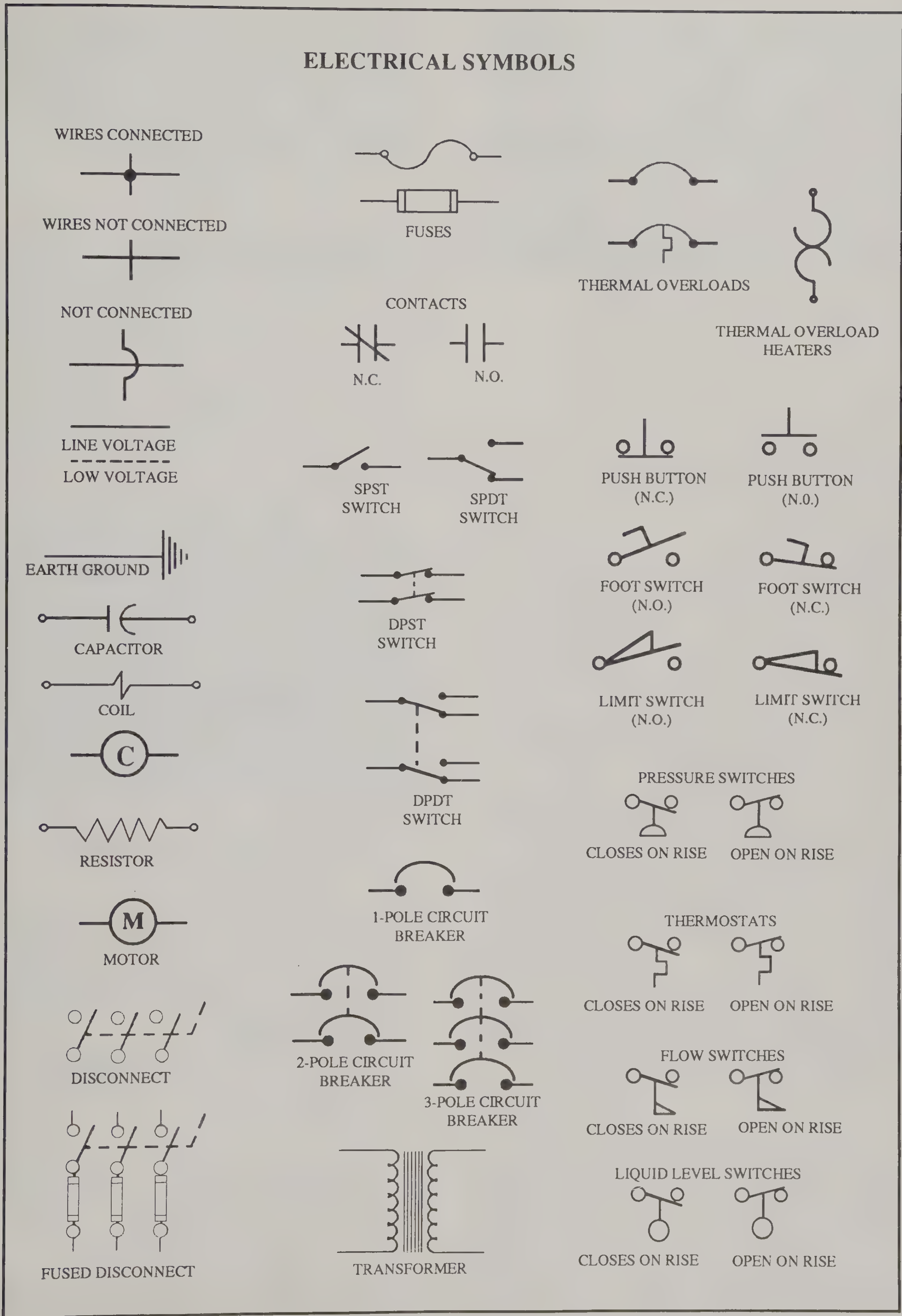


Fig. 22-52. A sampling of some of the electrical symbols commonly used on schematic diagrams.

power supply lines are drawn parallel to form the side rails of the ladder, and loads are drawn between the power source lines, forming the rungs. See Fig. 22-53. Various switches and fuses are located on the rungs as needed to control and protect the loads. All components (motors, switches, fuses) in the diagram are indicated by electrical symbols.

Reading a schematic requires more knowledge of electricity and electrical components than is needed to use a pictorial. The schematic does not look like the actual components and wiring in the unit. The technician must be able to relate this information to the actual unit (via the pictorial). To use a schematic diagram effectively, the technician must know the unit components and their corresponding electrical symbols. Most schematic diagrams contain a legend, or "key,"that describes the abbreviations and components.

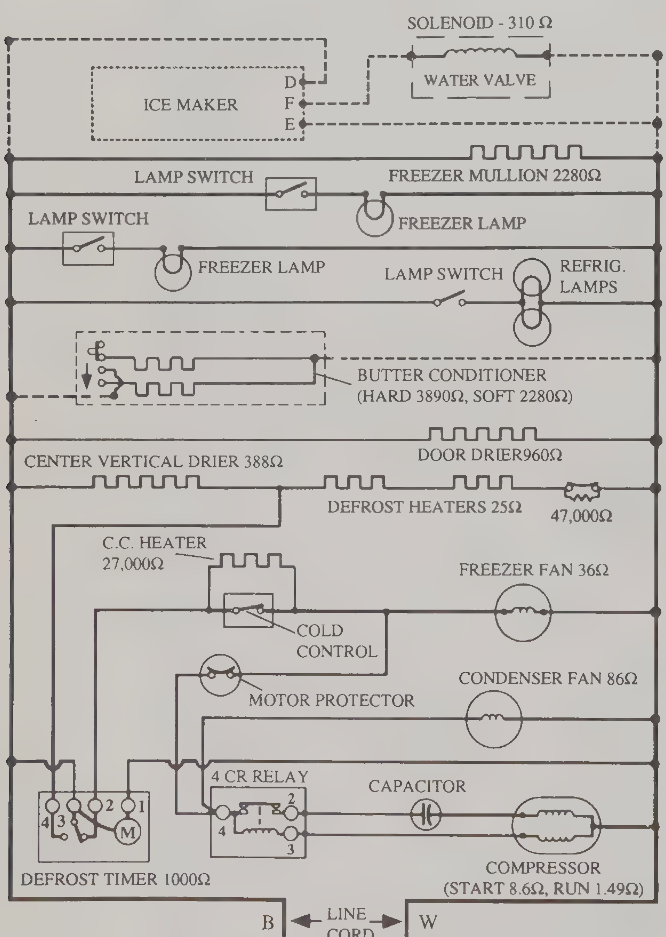


Fig. 22-53. An electrical schematic diagram is often referred to as a ''ladder diagram,'' since there is a single load on each ''rung.'' This is the schematic for the refrigerator-freezer shown in Fig. 22-51. (Frigidaire)

SUMMARY

This chapter introduced the variety of controls used to start and regulate the operation of motors. These controls are a common and necessary part of every refrigeration and air conditioning system. The technician must be very familiar with the troubleshooting and repair of motor control and circuit protection devices.

Each type of control and its use in different systems was explained, along with the electrical connections needed for proper operation. Instructions on selecting and troubleshooting various types of relays and contactors was included.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. A solenoid valve operates on the principle of __________.
2. Are relays used to control power supply to large loads or small loads?
3. Are contactors used to control power supply to large loads or small loads?
4. If the compressor starts when using a test cord to bypass the relay, is the relay working properly or is it defective?
5. True or false? Contactors are rated according to maximum amperage through the coil.
6. Power supply to the contacts of a contactor is connected to terminals labeled __________.
7. The electrical circuit controlling power supply to the contactor coil is called the __________ circuit.
8. How many switches can be connected into the circuit controlling power supply to the contactor coil?
9. What is the basic difference between a contactor and a line starter?
10. The overload contacts on a line starter are connected in __________ with the coil.

Chapter 23

MOTOR CONTROLS

After studying this chapter, you will be able to:

- *Identify and adjust primary motor controls.*
- *Troubleshoot thermostatic and pressure-type motor controls.*
- *Install and properly adjust safety controls.*
- *Troubleshoot safety controls.*
- *Recognize and properly adjust pumpdown cycles.*
- *Install and troubleshoot oil pressure safety controls.*

NEW WORDS

crimp
cut-in point
cut-out point
differential
dual-pressure motor control
erratic
fan cycle control
head-pressure safety control
heat load
logging
low-pressure motor control
net oil pressure
oil pressure safety control
oversized
pressure-operated switches
primary control
pumpdown cycle
riser
secondary control
sensing element
setpoints
stage
temperature range
thermostats

PRIMARY CONTROLS

Two types of motor controls are used to provide automatic operation of the condensing unit: thermostatic (temperature-sensitive), and pressure-type (pressure-sensitive). One or the other is found on every refrigeration system. These ***primary controls*** are used to start and stop the condensing unit when certain temperatures or pressures are reached. They include a switch that controls the power supply to the condensing unit. When the switch closes, the unit runs; when the switch opens, it stops.

The technician *must* understand the purpose and operation of these motor controls. Knowing the purpose of the control, how it operates, and how it is connected into the circuit makes troubleshooting easier and more accurate.

Thermostats are often used as the primary control for system operation. Other thermostats may function as *secondary* controls for individual operation of such devices as the condenser fan, evaporator fan, solenoid valves, and defrost heaters.

Like thermostats, ***pressure-operated switches*** are often used as the primary control of the system. They also may be used as safety controls to protect the system from high head pressure, loss of refrigerant, and low oil pressure. Troubleshooting these controls and making needed adjustments is an everyday task for the HVAC technician.

THERMOSTATS

Thermostats have a switch that opens and closes its contacts according to temperature changes. Thus, they can be used to automatically turn the condensing unit on and off as set temperatures are reached. Thermostats are available in many different shapes and styles to meet different applications. See Fig. 23-1. While thermostats may look different, all function in the same way: they open or close a set of contacts according to changes in temperature.

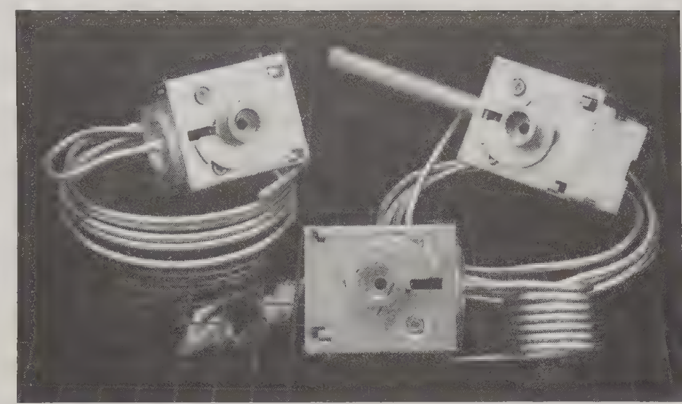


Fig. 23-1. Thermostats are provided in a number of different forms, but all perform the same job of opening or closing a switch in response to temperature change. (Ranco)

Thermostat contacts may *close* on rise in temperature, or *open* on rise in temperature. The type that closes on rise is used in cooling applications; the type that opens on rise is used in heating applications. See Fig. 23-2.

Thermostatic motor controls

All refrigeration systems are ***oversized*** (have more capacity than the minimum needed) to permit them to lower the temperature to a certain point and then shut off. When temperature rises to a certain point, the system is turned on. Heat removal occurs only while the system is running. A thermostat is used to cycle the system on and off, and thus maintain a temperature level in a desired range.

Thermostat sensing elements

The ***sensing element*** of a thermostat consists of a bellows (movable part), a capillary tube (connecting link), and a sensing bulb that holds a refrigerant. See Fig. 23-3. The refrigerant in the sensing element may be in a vapor or a liquid state. Different types of charges are used to achieve special operating characteristics.

Location of the sensing bulb determines what temperature is being controlled. Some sensing elements are designed for controlling air temperature, others for evaporator temperature (evaporator-sensitive), still others are submerged in liquid. Before replacing or making adjustments to a thermostat, you must know the sensing bulb location.

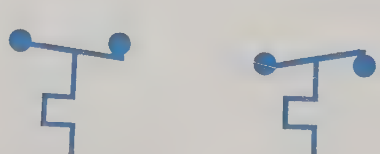


Fig. 23-2. Schematic symbols for thermostats. Those that close on a rise in temperature are used for cooling (refrigeration and air conditioning) applications, while those that open on a rise in temperature are used in heating applications.

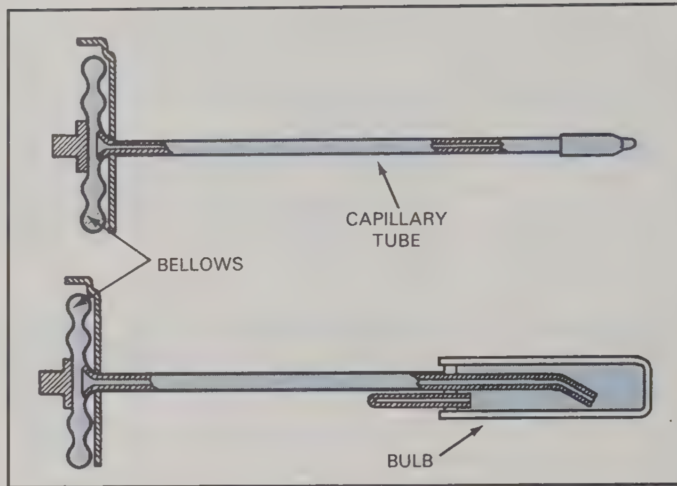


Fig. 23-3. As a refrigerant inside a capillary tube or bulb expands or contracts in response to a temperature change, the thermostat bellows moves. The movement opens or closes a switch when the temperature change exceeds selected levels.

Sometimes the bulb is omitted and the capillary tube itself becomes the sensing element. The capillary tube will vary in length. The tube end may be straight or formed in the shape of a bulb. See Fig. 23-4. Capillary tubes without bulbs are generally used on such appliances as household refrigerators, window air conditioners, or home food freezers. Twisted, coiled, and solid bulbs are often used in commercial refrigeration applications, such as food freezers or walk-in coolers.

Thermostatic control terminology

To understand motor controls, you must be familiar with the terms used to describe the operation of these controls. The temperature setting that causes the contacts to *close* is called the ***cut-in point.*** The temperature

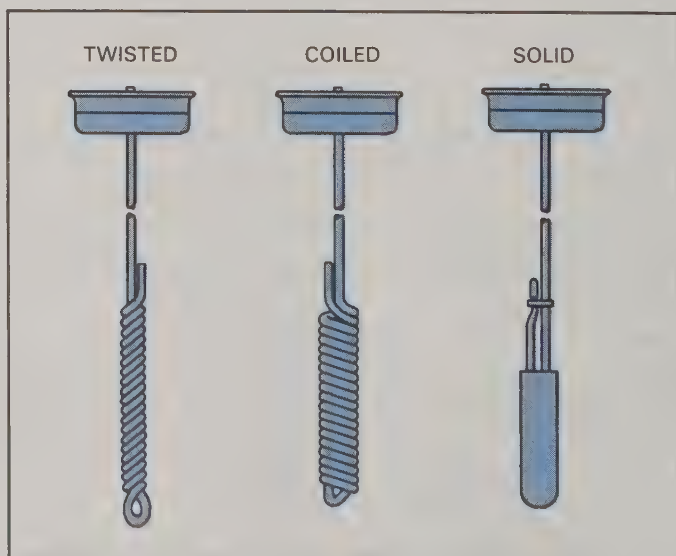


Fig. 23-4. On commercial refrigeration equipment, bulbs in twisted, coiled, or solid form are used.

setting causing the contacts to *open* is called the ***cut-out point.*** The difference between cut-in and cut-out is called ***differential.***

For example, a thermostat having a cut-in of 38°F (3°C) and a cut-out of 32°F (0°C) would have a differential of 6°F (38 - 32 = 6) or 3°C (3 - 0 = 3). Most domestic refrigeration thermostats have a fixed differential of 5°F or 6°F. Room thermostats for heating and air conditioning operate in a narrower range, with a fixed differential of 1.5°F to 2°F.

Range adjustment. The dial (or knob) on a domestic thermostat is a range adjustment. This range adjustment moves the cut-in and cut-out *equally* higher or lower. See Fig. 23-5. Turning the range adjustment to a colder setting lowers ***both setpoints*** (cut-in and cut-out), so the system will maintain the lower temperature level. Turning the range adjustment to a warmer setting will cause the system to maintain the higher temperature level.

Control temperature ranges. Controls are designed to operate within a specific ***temperature range.*** These temperature ranges are rather general, but fall into five areas of application.

- **High-temperature application:** between 90°F and 55° F (32°C and 13°C). Usually associated with room heating and air conditioning systems.
- **Medium-temperature application:** between 55°F and 32°F (13°C and 0°C). Normally associated with refrigerators and other types of coolers.
- **Low-temperature application:** between 5°F and -50°F (-15°C and -48°C). Usually associated with freezers.
- **Ultra-low-temperature application:** between -50°F and -250°F (-48°C and -157°C). Associated with industrial and commercial fast-freezing systems.
- **Cryogenic application:** between -250°F and -459°F, or absolute zero (-157°C and -273°C). Usually associated with laboratory and research systems.

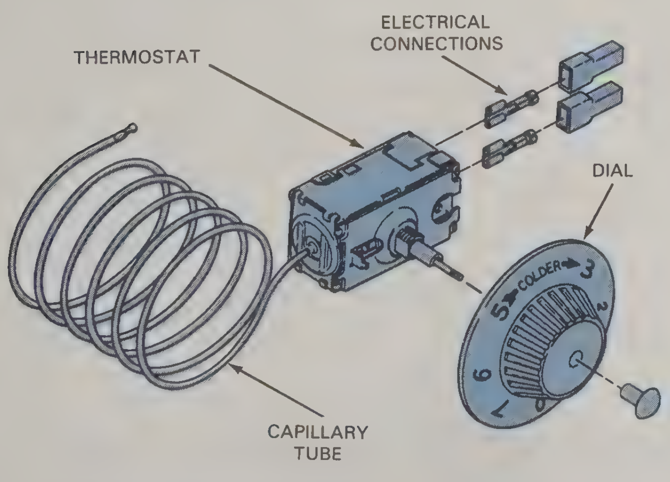


Fig. 23-5. Turning the dial on a domestic thermostat performs a range adjustment. The cut-in and cut-out temperatures are higher or lower, depending upon the adjustment, but the *differential* does not change. (Ranco)

Domestic thermostats

As noted, the range adjustment on domestic thermostats is usually limited to a few degrees either way (warmer or colder). A domestic thermostat is designed to operate with the range adjustment knob close to mid-position. It is poor practice to operate any system with the range adjustment set at either minimum or maximum. The thermostat cannot operate properly at either extreme. Typically, turning the knob all the way to the right is the warmest position and turns the thermostat off (contacts constantly open). Turning the knob all the way to the left moves it to the coldest position and the thermostat cannot open (contacts constantly closed).

Some manufacturers of domestic controls include two small screws identified as "altitude adjustment screws." Such altitude adjustments are unnecessary and should be ignored. The slight difference in pressure due to high altitude will equally affect both cut-in and cut-out. A small change in range adjustment automatically compensates for altitude.

Wiring connections. While thermostats are used to control the power supply to the condensing unit, they are normally located remote from the condensing unit. Connecting wires can be any length.

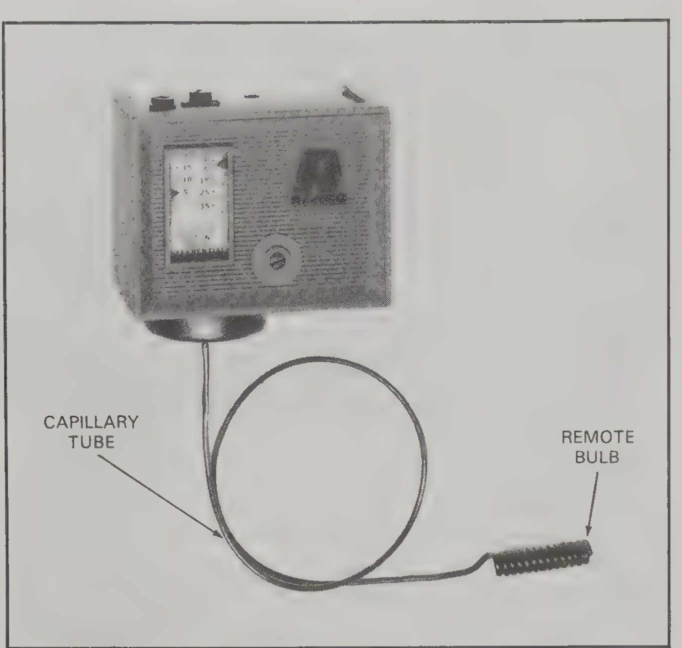
Thermostats normally have two terminals; each terminal is internally connected to one side of the switch. These terminals can be either push-on-type or screw-type. Wiring connections should be tight and well-insulated, since loose wiring connections are a primary cause of burned wires and component damage. Most thermostats include an extra (third) terminal, which is connected to the metal case and used for making the safety ground (green wire) connection.

For single-phase domestic systems, the thermostat switch is connected in series with one of the wires supplying power to the relay. This permits the thermostat switch to disconnect the relay from the power supply. It is poor practice to connect the thermostat in the neutral wire. It makes troubleshooting more difficult and can cause safety problems.

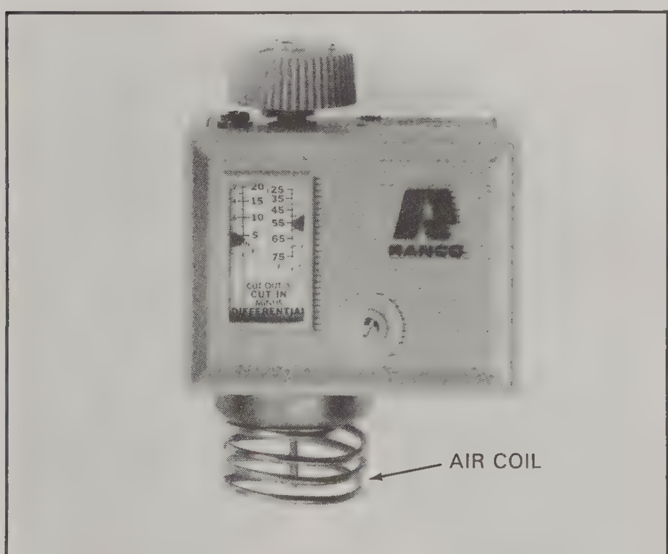
Commercial thermostats

Commercial thermostats, Fig. 23-6, are designed for a wide range of temperatures and have fully adjustable control settings. Two heavy duty adjustment screws are located on top of the control for moving the pointers. A separate calibrated scale is provided for each pointer and is located directed below each screw. This permits the technician to control a wide temperature range, with the cut-in and cut-out easily adjusted to maintain desired temperatures.

Adjusting controls. Commercial thermostat adjustments must be performed in proper order to achieve the desired results. As you face the control, the left screw changes the differential, while the right screw is the range adjustment. The range adjustment changes cut-in



A



B

Fig. 23-6. Typical commercial thermostats. Note the separate scales for setting cut-in temperature and differential. A–Thermostat with remote sensing bulb. B–Thermostat with air coil for sensing. (Ranco)

and cut-out equally. The differential screw changes *only* the cut-out temperature.

First, adjust the range screw until the desired cut-in temperature is indicated on the scale. (Both pointers will move when making range adjustments.) Next, adjust the differential screw to obtain the desired differential setting. This screw moves only the pointer on the differential scale. In a cooling application, *the cut-out equals cut-in minus differential.* See Fig. 23-7.

For example, consider a walk-in cooler that has an air-sensitive thermostat mounted on the inside wall to sense temperature of return airflow. See Fig. 23-8. Air temperature should be maintained between 38°F and 32°F (3°C and 0°C). The range adjustment screw is used to move the cut-in pointer to the 38°F mark on the range scale. The differential screw is then adjusted to move its pointer to the 6° mark on the differential scale. With a differential of 6°, the cut-out will be 32°F (0°C).

Some commercial motor controls have a *cut-out screw and scale* instead of a differential screw. The cut-out

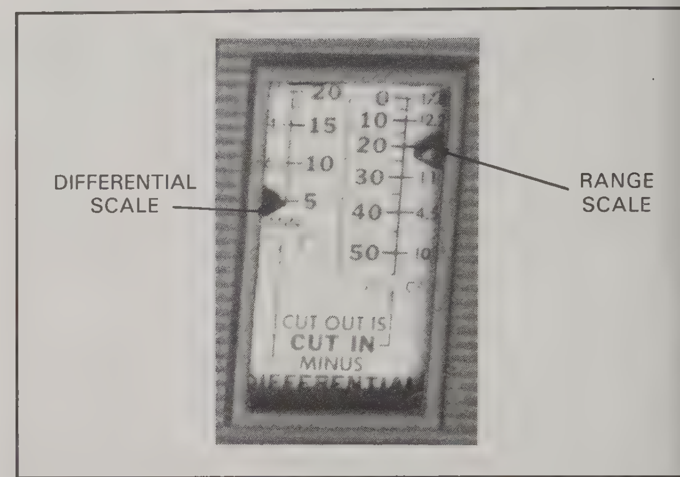
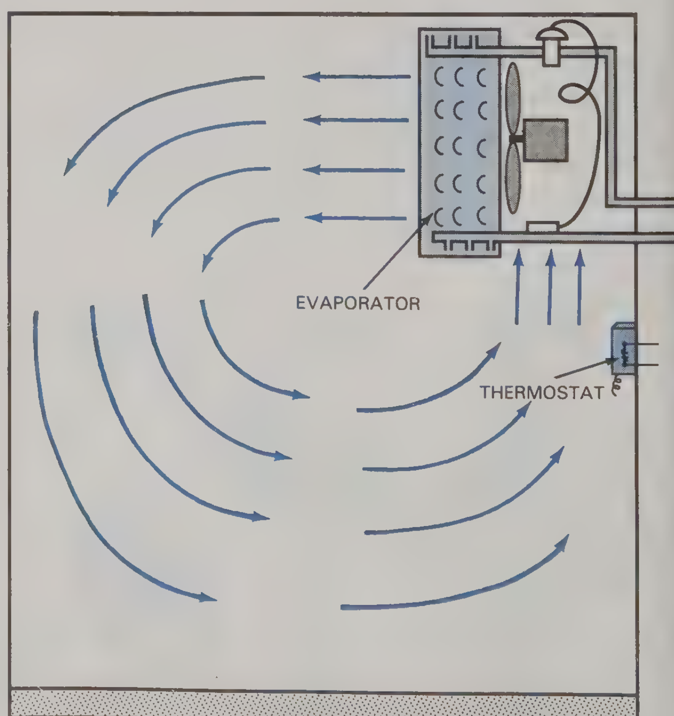


Fig. 23-7. The range scale pointer indicates the cut-in temperature, and is adjusted first. The differential pointer is then moved to set the desired cut-out temperature. On the thermostat illustrated, the cut-in temperature is 20 °F, and the differential is 5 °, so the cut-out temperature is 15 °F. (Ranco)



Fig, 23-8. The thermostat in this walk-in cooler is positioned to monitor the temperature of the return air. When properly adjusted, it will maintain the temperature inside the cooler in a range from 32 °F to 38 °F (0 °C to 3 °C).

screw directly establishes the cut-out point according to the position of the pointer on the scale. Whenever you deal with a commercial thermostat, examine it carefully to determine if the left screw is a cut-out or differential screw. The settings are different.

Information printed at the bottom of the scale will identify the type of scales used. Controls using a differential screw will read "Cut-out is cut-in minus differential." Controls using a cut-out screw will label one scale "cut-out" and the other a"cut-in."

Wiring connections. On commercial (three-phase) systems, the thermostat switch is connected in series with the coil on the contactor (or line starter). See Fig. 23-9. The thermostat controls power supply to the coil, which (in turn) controls power supply to the compressor. The thermostat is located close to the area where the temperature is being controlled, due to limited length of the sensing element. Two wires connect the thermostat terminals to the contactor coil.

Disadvantage of thermostatic motor controls

Since the thermostat operates according to temperature of the sensing element, it may call for operation when the system is having problems. For example, a thermostat can require the system to operate when some or all refrigerant is lost. If a leak occurs on the low-pressure side of the system, operation of the system will allow air and moisture to be drawn in and cause major problems. Relying strictly on thermostatic control may cause the system to self-destruct. Safety controls are often added to the system to keep it from operating if a problem develops.

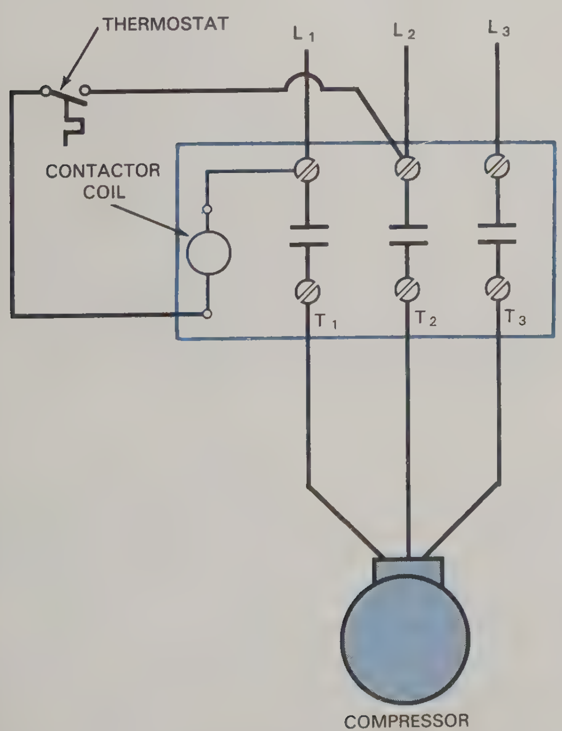


Fig. 23-9. The thermostat on a three-phase system is connected in series with the coil to control the power supply to the contactor.

Domestic systems such as refrigerators, freezers, and window air conditioners rely upon the *compressor overload* to provide safety protection. However, prolonged cycling on the overload will result in compressor failure. Commercial installations normally include additional safety controls to protect the system. Such controls are explained later in this chapter.

Troubleshooting thermostats

Thermostats are generally reliable. Most problems are related to improper settings, a sensing element that is not making good contact, or an element that has lost its refrigerant charge. Sometimes, vibration or rubbing will wear a hole in the capillary tube, allowing loss of the bulb charge.

The thermostat switch can be checked with a voltage tester, after making certain that the contacts *should* be closed. Check for voltage from each thermostat terminal to a good ground. If the tester shows voltage at both terminals, the contacts are closed. If the tester voltage at just one terminal, the contacts are open.

Another procedure can be performed as a double-check by placing the voltage tester probes at each thermostat terminal. If the tester lights up, the contacts are open. If the tester does *not* light up, another switch may be open downstream of the thermostat (such as an overload) and thus give a false reading.

The thermostatic motor control is a primary controlling device. Such controls are often incorrectly diagnosed as defective, because other switches are often wired in series with them. These switches (often safety controls) can prevent the system from operating. For proper control by the thermostat, power supply should always be available at one (inlet) terminal of the thermostat. Sometimes, however, an overriding control such as a defrost time clock may prevent power supply from reaching the thermostat. Defrost systems and time clocks are explained in Chapter 24.

PRESSURE-TYPE MOTOR CONTROLS

The pressure-type motor control, Fig. 23-10, is widely used on commercial systems because it is accurate, dependable, fully adjustable, and located at the condensing unit. This location is convenient for the technician and helps prevent tampering with the control. Adjustments are critical, however, and vary from one system to another. Adjustments can be performed effectively only by a technician who is fully aware of the temperature-pressure relationship.

Principles of operation

The pressure-type motor control includes an electrical switch that is opened or closed by pressure on a diaphragm. See Fig. 23-11. The diaphragm is a thin metal

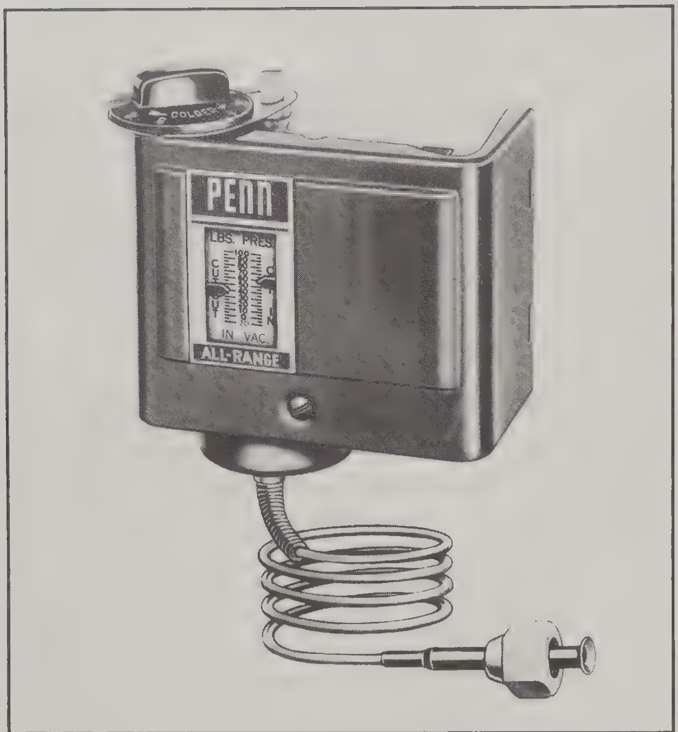


Fig. 23-10. A low-pressure control that opens or closes a switch when pressure causes movement of a diaphragm. This control has specific cut-in and cut-out settings, rather than using a differential to determine the cut-out pressure. (Penn Controls)

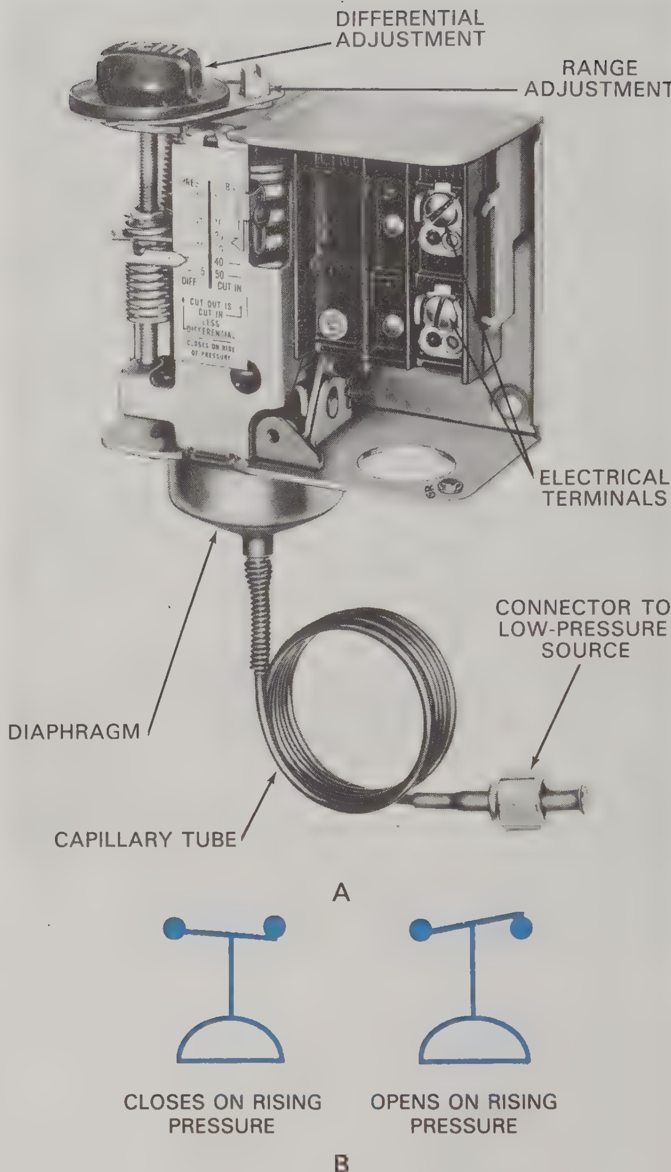


Fig. 23-11. Pressure switch and symbols. A–Low-pressure switch with cover removed to show construction. The electrical terminals are in series with the internal switch that is opened or closed by movement of the diaphragm. This control permits setting of the cut-in pressure and a differential, as indicated on the scales.(Penn Controls) B–Schematic symbols for pressure switches. In refrigeration applications, thermostats that close a switch on a pressure rise are normally used.

disc about 1-1/2 inches in diameter, located in an assembly attached to the bottom of the control. A capillary tube connects the diaphragm assembly to the low-pressure side of the system. This low-pressure connection is usually made on the compressor body. Either an increase or a reduction of low-side pressure will cause the diaphragm to move. Movement of the diaphragm operates the switch through a mechanical connection. Most pressure controls have two electrical terminals connected in series with the internal switch.

In terms of function, the pressure control is much like a thermostatic motor control. However, scales on thermostats are calibrated in degrees Fahrenheit (°F) or degrees Celsius (°C), while pressure controls are in pounds per square inch gauge (psig) or kilopascals (kPa). Product temperature can be maintained by controlling low-side pressures in the system. This is not difficult, but certain principles regarding low-side pressures must be fully understood. The technician must be able use a *temperature-pressure chart* to convert temperature to pressure.

Low-side pressures

The sole purpose of any refrigeration system is to create a temperature difference so that heat can travel through the evaporator to be absorbed by the vaporizing refrigerant. This temperature difference can only exist when the system is running. Once the system shuts off, the temperature differences quickly disappear. During the "off" cycle, refrigerant pressure (low-side pressure) equals the temperature of the air moving through the evaporator. As air temperature inside the cabinet increases, low-side pressure increases, as well.

During the "on" cycle, the operation of the system quickly establishes a temperature difference that permits heat to travel from the air to the evaporator, and then to the refrigerant inside the evaporator. The refrigerant is about 10°F (5°C) colder than the evaporator and the evaporator is about 10°F (5°C) colder than the air. As

the temperature of the air becomes colder, the evaporator and refrigerant also become colder, thus maintaining the temperature difference during the run cycle.

Freezer pressure settings

As an example, consider a walk-in freezer using R-502 and low-pressure motor control to maintain cabinet air temperatures that range from -10°F to -20° F (-23°C to -29°C).

Cut-in point. The cut-in point is determined from the temperature-pressure chart; no temperature difference exists during the off cycle. With the system off, cabinet air temperature slowly rises until air, evaporator, and refrigerant are the same temperature, -10°F (-23°C). At this temperature, the pressure for R-502 (as shown on a standard temperature-pressure chart) is 23 psig (159 kPa). This becomes the cut-in point, so the range adjustment screw is moved to show cut-in on the pressure switch scale at 23 psig.

At start-up, the air temperature is -10°F (-23°C) and the condensing unit quickly establishes the desired 20°F (11°C) air-to-refrigerant temperature difference. The refrigerant temperature becomes -30°F (-34°C). A low-pressure gauge connected to the system would reflect this temperature difference by quickly dropping from the cut-in pressure of 23 psig (159 kPa) to 9 psig (62 kPa).

The system is designed to maintain the 20°F temperature difference during the run cycle. While the system is running, air temperature slowly drops from -10°F to -20°F (-23°C to -29°C). At the same time, low-side pressure slowly reduces from 9 psig to 4 psig (62 kPa to 28kPa), and refrigerant temperature from -30°F to -40°F (-34°C to -40°C).

Cut-out point. The cut-out point is determined by subtracting 20°F (11°C) from the desired cut-out *air* temperature. When the air temperature reaches -20°F (-29°C), refrigerant temperature is -40°F (-40°C) and low-side pressure is 4 psig (28 kPa). The cut-out pressure control is adjusted to read 4 psig. If the control has a *differential screw*, the differential is set at 19 psig (23 - 4 = 19). In metric terms, the differential would be 103 kPa (131 - 28 = 103).

Pressure control settings

A *gauge manifold* should be installed when making adjustments to pressure-type motor controls. Gauge readings are more accurate than the pointers and scales on the controls. To set the cut-in, do not wait for cabinet air temperature to reach ambient. Instead, use the gauge manifold to bleed pressure from the high side to the low-pressure side. This raises low-side pressure to the cut-in point rather quickly. This procedure is also used to double-check the cut-in setting.

The cut-out is quickly set by using the suction service valve (SSV) to restrict incoming suction gas. Frontseat the valve stem, then crack it open just enough to limit the incoming pressure at the desired cut-out point. Set the control (cut-out or differential) while the incoming low pressure is controlled. After the cut-out is firmly established and double-checked, backseat the suction service valve to remove the gauges and return the system to normal operation.

Cooler pressure settings

Consider a walk-in dairy cooler using R-12 and operating with cabinet air temperatures of 39°F to 32° F (4°C to 0°C). The system cut-in pressure is set for 36 psig (248 kPa), because no temperature difference exists when the system is off. The temperature-pressure for R-12 at 39°F is 36 psig.

Cut-out is determined by the temperature of the *refrigerant* when air temperature is 32°F (0°C). The refrigerant is about 20° colder than air temperature, so the control would be set to cut-out at 16 psig, which is the pressure equivalent of 12°F(-11°C). A differential screw is set for 20 psig (36 - 16 = 20), or in metric terms, 138 kPa. See Fig. 23-12.

Adjusting for pressure drop. When setting the cut-out on a pressure-type motor control, an allowance must be made for pressure drop through the suction line. The suction is strongest at the compressor when the piston makes its downstroke. Suction line pressure at the compressor is about 2 psig (14 kPa) *lower* than evaporator pressure.

Proper sizing of the suction line limits pressure drop to 2 psig. Pressure drop may be slightly higher if the suction line is very long, or contains many elbows,

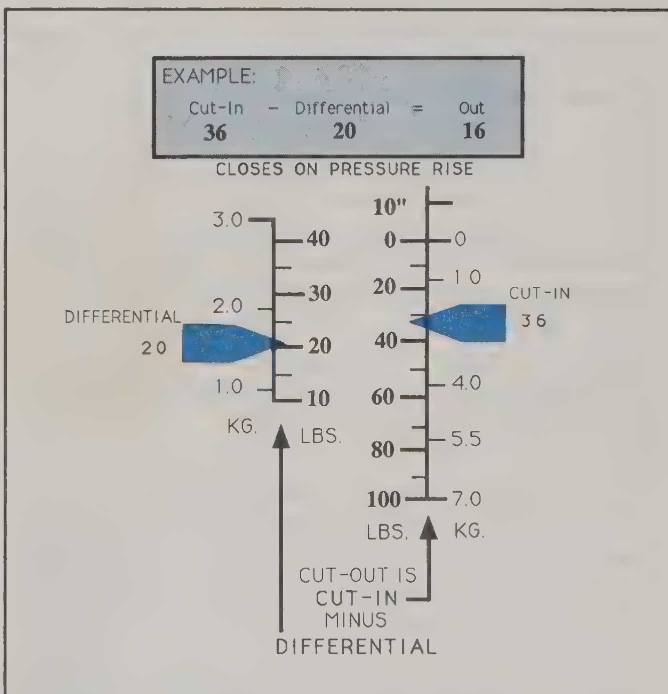


Fig. 23-12. Pressure switch control settings for a walk-in cooler using R-12. With a cut-in of 36 psig and a differential of 20 psig, the cut-out is 16 psig.

valves, and risers. A *riser* is a vertical section of the suction line.

To allow for pressure drop, subtract 2 psig from the desired cut-out value just before setting the control. In the freezer example, cut-out was determined to be 4 psig (28 kPa). Thus, the cut-out setting on the motor control must be 2 psig (4 - 2 = 2) to compensate for pressure drop. In the dairy cooler example, the cut-out setting would be reduced from 16 psig (110 kPa) to 14 psig (97 kPa).

Pressure drop affects only cut-out because pressure drop disappears during the off cycle. Pressure drop cannot occur unless the compressor is running.

Allowing for temperature differences. The temperature difference of 20°F between the air and refrigerant is a good guide. Some evaporators are more efficient than others and this temperature difference could be slightly more, or slightly less. After setting cut-in and cut-out on the pressure motor control, it is good policy to place an accurate thermometer inside the cabinet to check air temperature at both setpoints. Minor adjustments to the cut-out may be necessary to compensate for excess pressure drop or temperature difference through the evaporator.

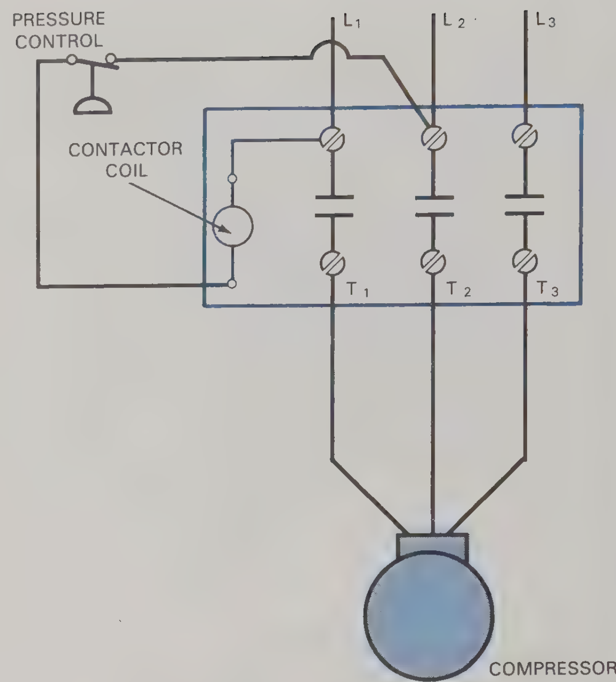


Fig. 23-13. The pressure control on a three-phase system is connected in series with the coil to control the power supply to the contactor.

Single-phase wiring connections

The pressure-type motor control, as noted earlier, is a primary control. Its switch is used to control power supply to the condensing unit. These controls usually have two screw-type terminals, which are internally connected to the two sides of the switch. The wiring connections are performed exactly like a thermostatic motor control, but the wires will be much shorter because a pressure control is always located very close to the compressor. Wiring connections are usually performed inside the compressor terminal box, or inside the electric panel mounted on the condensing unit.

Three-phase wiring connections

The *low-pressure motor control* is the preferred choice on commercial systems, and is used to control power supply to the contactor coil. See Fig. 23-13. Both the contactor and the pressure motor control are located at the condensing unit, which makes wiring connections and troubleshooting easier. The pressure motor control switch is connected in series with one of the wires supplying power to the coil.

Troubleshooting pressure motor controls

Troubleshooting procedures for pressure controls are similar to those used with thermostats. The control is simply an electrical switch that operates according to low-side pressure at the compressor. The low-side pressures *must* be adequate for the control to operate properly.

System low on refrigerant. If the system is low on refrigerant, the low-pressure control will cause the system to short-cycle. The control switch opens and closes too quickly because the compressor is drawing gas out of the suction line faster than the expansion valve can feed liquid. Low-side pressure quickly drops to the cut-out point, the switch opens, then low-side pressure quickly rises to the cut-in point. Resetting the control does not solve the problem. The leak must be located and repaired, and then the system charged to full capacity again.

No refrigerant in system. If the system loses all its refrigerant, the control contacts remain open. Low-side pressure cannot build up sufficiently to close the contacts and start the motor-compressor. When the control contacts are open, the voltage tester will reveal power supply (voltage) only at the inlet terminal.

This feature of the system, shutting off when it is very low on refrigerant, is an advantage. If a leak occurs on the low-pressure side of the system, the control will shut the system off before it reaches a vacuum state that would allow contaminants to enter.

Defective pressure control. To properly diagnose a defective pressure motor control, the gauge manifold must be installed. These controls are usually reliable, but sometimes become *erratic* (irregular) in operation. A control that is unable to maintain pressure settings must be replaced. This condition is usually caused by abuse to the control.

A common pressure control problem is a leak in the capillary tube linking the control diaphragm to the compressor. This leak is caused by vibration or by rubbing of the capillary tube against another metal object. Excessive vibration can cause the copper capillary tube to become work-hardened and crack or break off. Rubbing, especially against a steel object, will quickly wear

a hole in the capillary tube, since steel is much harder than copper. The entire system charge can be lost by such a leak.

Repairing the control capillary tube. It is usually not necessary to replace the control when the capillary tube develops a leak. Unless the tube is leaking at a point very close to the diaphragm, it can be repaired. Repairing the capillary tube is much easier and quicker than replacing the control. Follow this procedure for repairing a leaking capillary tube:

1. Shut off power supply to the unit and install gauge manifold on the suction and discharge service valves. The unit must not be permitted to run while repairs are being made.
2. Frontseat the suction service valve to isolate the compressor. The compressor discharge valve reeds will prevent refrigerant backflow into the compressor.
3. Loosen the flare nut connecting the capillary tube to the compressor. Permit any pressure inside the compressor to escape *slowly,* since rapid escape of this pressure may result in severe oil loss.
4. Cut or break the capillary tube at the point of the leak and remove the flare nut and tubing from the compressor.
5. Use a 3- to 4-in. piece of 1/4-in. soft copper tubing to splice the capillary tube together. See Fig. 23-14. Use water-pump pliers to carefully ***crimp*** (squeeze closed) the openings at each end of the 1/4-in. copper tubing for easier brazing. Exercise care to prevent crimping the capillary tube.

The ends of the capillary tube must be inserted *at least* 1 in. into the 1/4-in. copper tubing to prevent the brazing alloy from plugging the capillary tube ends.

6. Braze each end of the 1/4-in. copper tubing to the capillary tube, allow to cool, and reconnect the flare nut to the compressor. Carefully arrange the repaired capillary tube to eliminate vibration and rubbing.
7. Backseat and then crack open the suction service valve. Add enough refrigerant gas (about 100 psig pressure) to check the brazed connections and the flare nut connection for leaks.
8. Restore power, then add the necessary refrigerant to bring the system to full capacity.

These procedures are adequate if the pressure control cut-out was high enough to prevent the system from operating in a vacuum. If the system *was* allowed to operate in a vacuum, atmospheric air and moisture were drawn into the system and further repairs are required. These repairs involve purging all remaining refrigerant (and air) from the system, repairing the leak, pressurizing enough to leak-check, then purging all pressure. Finally, the filter-drier must be changed and a thorough evacuation performed with a good vacuum pump before charging the system to full capacity. Failure to perform these repairs when air has entered the system will result in poor system performance and compressor burnout. This explains why the cut-out should occur *before* the low-side pressure enters a vacuum.

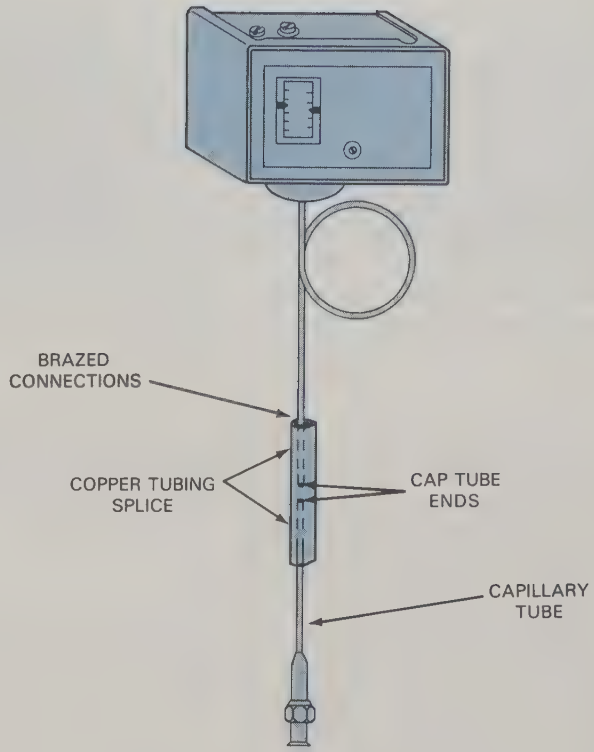


Fig. 23-14. Repair method for leaking capillary tube, using a piece of 1/4-in. copper tubing as a splice.

LOW-PRESSURE SAFETY CONTROL

The low-pressure safety control is used as a ***secondary control*** to shut off the system if the low-side pressure is reduced to unsafe levels. The low-pressure safety control is vital when the system uses a thermostat for temperature control. The thermostat is the primary control and the low-pressure safety control becomes a secondary (safety) control.

As noted, the low-pressure safety control will turn the system off when low-side pressure becomes too low. Most compressors rely upon the suction gas to cool the motor windings; if this cool gas is not available, the motor will overheat and cycle on the overload. The low-pressure safety control is often used to protect the system against loss of refrigerant and protect air conditioning systems and water chillers from suffering an evaporator freeze-up.

Commercial low-pressure *safety* controls are similar to the *primary* low-pressure control. In fact, the same control model can often be used for either purpose, because they are selected according to the range and differential scales. Therefore, the same control can serve different purposes. Fig. 23-15 illustrates some typical examples.

The low-pressure safety control may have a 36-in. or 48-in. capillary tube with a flare nut for connection to

PRESSURE CONTROLS	
RANGE SCALE	DIFFERENTIAL SCALE
12" TO 50 PSIG	5 TO 35
10" TO 100 PSIG	10 TO 40
50" TO 150 PSIG	10 TO 40

Fig. 23-15. As shown in this table, the range scales and differential scales overlap, allowing a given pressure control to be used as either a primary or secondary control.

the low-pressure side of the system. This connection is normally made at the compressor. The control contacts are designed to close on rising pressure and open once pressure falls to a certain point.

Wiring connections

The contacts for the low-pressure safety control are connected in series with the thermostat contacts. See Fig. 23-16. The thermostat cycles the unit under normal operating conditions, with the low-pressure safety control acting as a back-up. The contacts on both switches must be closed to run the system, but either switch can open and stop operation.

Pressure settings

The low-pressure safety control must not be permitted to interfere with normal operation of the system, yet

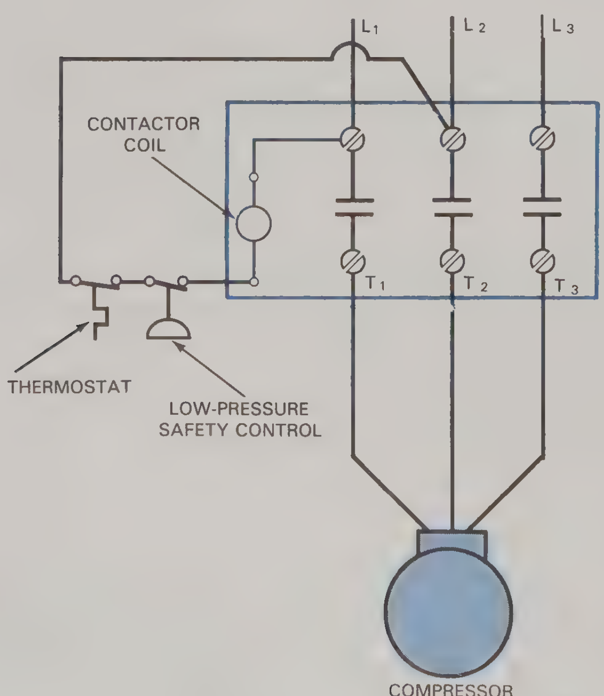


Fig. 23-16. In a thermostatically controlled system with a low-pressure safety control, the two controls are wired in series with the contactor coils. Both switches must be closed to operate the system. If either opens, the system will stop operating.

it must provide necessary protection. The control settings vary according to each system and refrigerant used. Pressure settings must protect the unit against loss of refrigerant, while the differential must be sufficient to prevent short-cycling.

When the system becomes low on refrigerant, the compressor quickly reduces low-side pressure. When the compressor shuts off, low-side pressure increases rather quickly, due to higher temperature at the evaporator. A close differential would permit the system to short-cycle during loss of refrigerant. The safety control is set to cut out just before the low-side pressure enters a vacuum. A wide differential places the cut-in at a point requiring more time for the low-side pressure to increase before reaching the cut-in point. When trying to calculate the settings on a low-pressure safety control, it is best to think backwards (from cut-out to cut-in).

For example, consider a walk-in cooler using a thermostat to control air temperatures between 37°F and 32°F (3°C and 0°C). The refrigerant used is R-12. If a leak occurs, the low-side pressure must be prevented from entering a vacuum. The low-pressure safety control cut-out should be established at a point just above a vacuum (between 2 psig and 5 psig, or 14 kPa and 34 kPa). The differential must be about 20 psig to 25 psig (138 kPa to 172 kPa) to prevent short-cycling, so the cut-in should be set at about 30 psig (207 kPa). After calculating the proper setpoints, the control is adjusted by first setting the cut-in, then the differential.

Control settings of 25 psig (cut-in) and 3 psig (cut-out) do not interfere with normal operation of the system. The safety cut-in pressure is below the cut-in temperature of the thermostat, and the safety cut-out pressure is below the cut-out temperature. The corresponding low-side pressures for the temperatures at which the thermostat opens and closes are 34 psig (234 kPa) for cut-in and 14 psig (97 kPa) for cut-out.

Air conditioning application

Low-pressure safety controls are often used on air conditioning and water chillers to prevent evaporator freeze-up. These systems use a thermostat as a primary control to maintain proper air temperatures. When the evaporator freezes up on an air conditioner or chiller, it becomes possible for liquid refrigerant to flood back to the compressor. Even though the system has problems, the thermostat will continue to call for cooling. Since water expands when it freezes, evaporator tubes on a chiller can be badly damaged by a freeze-up.

The refrigerant of choice for high-temperature (air conditioning) applications is R-22. Low-side pressure rarely drops below 58 psig (400 kPa), or in temperature terms, 32°F (0°C), because the cooling job is finished as the system is ready to shut off. With refrigerant temperature at 32°F (0°C), the evaporator is 42°F (6°C), and the "air off" the evaporator is 52°F (11°C). Frost and ice cannot accumulate on the evaporator because

the evaporator temperature is above the freezing point of water. The 52°F air off (supply air) indicates that air on (return air) temperature will be 72°F.

The cool air off is directed by supply air ducts to the living space. See Fig. 23-17. Warm air flows back to the evaporator (by return air ducts), where it is again cooled and sent back to the living space. This recirculation of air is continuous until the space air is cooled to the cut-out point on the thermostat. The blower provides the necessary force to move air through the evaporator and the ducts.

Air conditioning systems are designed for the evaporator to produce 16°F to 20°F (9°C to 11°C) difference between the temperature of air on and air off the evaporator. In air conditioning work, the technician uses the temperature of air off the evaporator (supply air) to calculate temperature-pressure of the refrigerant. Air conditioning evaporators are designed to control temperature of air off. The evaporator is 10°F (5°C) colder than air off, and refrigerant temperature is 10°F (5°C) colder than the evaporator.

For example, consider a central home air conditioner that has been turned off during vacation time. Upon returning home, the owner finds that the interior house temperature is 85°F (29°C). The owner immediately turns on the air conditioner to cool the house to an acceptable level (usually 72°F, or 22°C).

When the air conditioner starts, the temperature of air on the evaporator is 85°F (29°C) and the air off is 65°F (18°C). With a 65°F air off temperature, the refrigerant temperature is 45°F (7°C) and the low-side pressure is 76 psig (524 kPa). As the temperature of air on is reduced, air off temperature is also reduced, and refrigerant temperature decreases. Eventually, the air on temperature becomes 72°F (22°C), the thermostat cut-out point. Air off is 52°F (11°C) and refrigerant temperature is 32°F (0°C). Evaporator pressure is 58 psig (400 kPa).

In this example, the lowest evaporator temperature was 42°F (6°C), well above the freezing point of water. However, if evaporator temperature drops below 32°F (0°C), ice and frost will accumulate on the evaporator and proper air flow will be lost. When evaporator air flow is reduced, the ***heat load*** is also reduced, and the evaporator becomes colder and colder. The heat load is necessary to maintain proper system pressures.

The low-pressure safety control on air conditioning is set to cut out at 40 psig to 45 psig (276 kPa to 310 kPa). At 40 psig, refrigerant temperature is about 17°F (-8°C) and the evaporator is 27°F (-3°C). Any evaporator operating below 32°F will accumulate frost. The air conditioner must be stopped before the freeze-up becomes severe.

Troubleshooting

Problems with the low-pressure safety control are rare. If the switch is bad, the control must be replaced. Most often, however, the problem is a capillary tube that is leaking due to vibration or rubbing. Corrective procedures for leaking capillary tubes were described

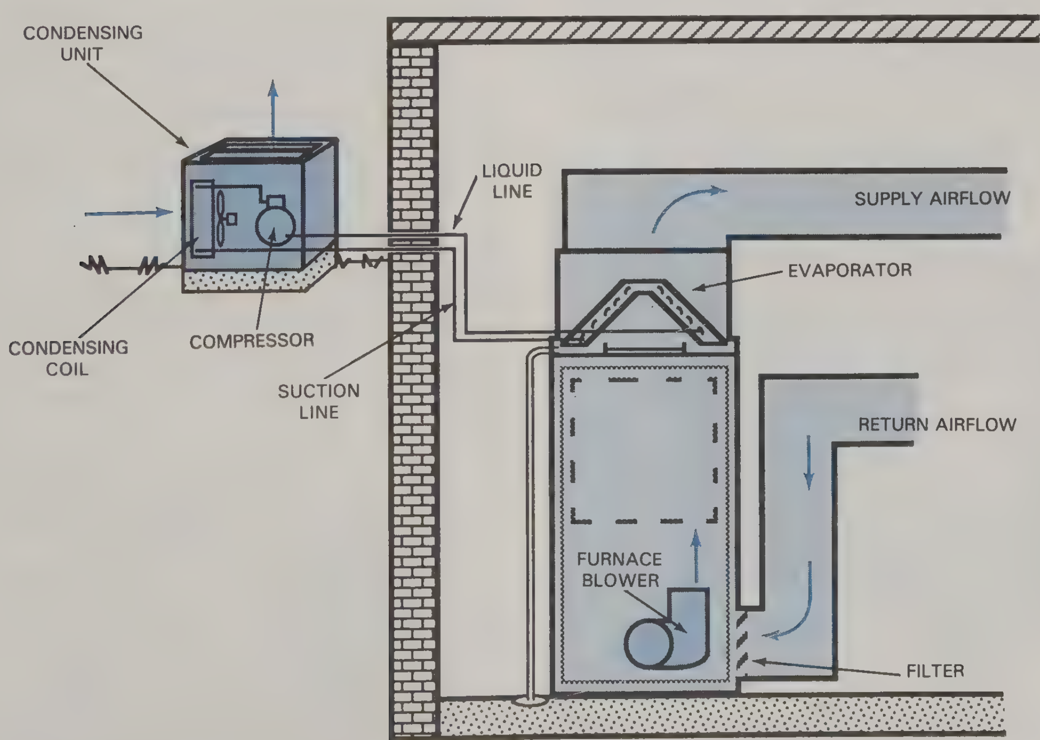


Fig. 23-17. A remote (split) system for residential air conditioning places the condensing unit outdoors. The furnace blower moves air through the evaporator coil, where it is cooled and distributed to living space through the supply duct system.

earlier. The low-pressure safety control serves as a warning device that pressure is below safe limits. The actual problem is usually elsewhere, not with the control.

Some problems that will cause the system to have low-pressure are:

- Low refrigerant level.
- Evaporator freeze-up.
- Evaporator fan not running.
- Restricted airflow due to dirty return air filters.
- Dirty evaporator due to missing air filters.
- Moisture in the system, freezing at refrigerant control.
- Faulty superheat setting on TEV.
- Restriction at filter-drier.
- Low head pressure due to low ambient temperature.

HEAD-PRESSURE SAFETY CONTROL

The ***head-pressure safety control*** is a device that will shut off the system if head pressure exceeds proper limits. High head pressure results in poor system performance and damage to the compressor. High head pressure is rather common; this safety control protects the system when it occurs.

The commercial high-head-pressure safety control looks much like a low-pressure safety control. See Fig. 23-18. The head-pressure safety control is designed for the contacts to open on *rising pressure*. The capillary tube is connected to the high-pressure side at the compressor. Depending upon the range scale, the same control can be used for R-12, R-22, or R-502. See Fig. 23-19.

The head-pressure safety control is available with either automatic reset or manual reset. In automatic reset, the control contacts automatically close when head pressure drops to the cut-in setpoint. This means that the control turns the compressor on and off when-

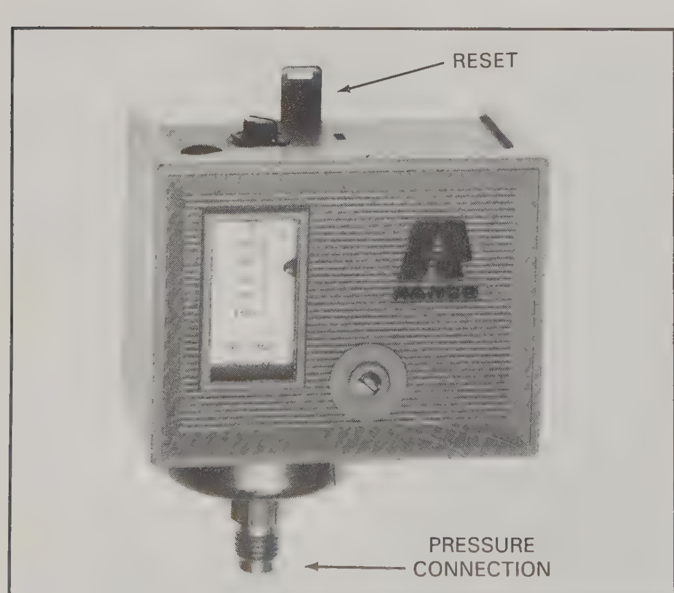


Fig. 23-18. A head-pressure safety control with a manual reset button. Note that the scale shows only cut-out pressure. (Ranco)

HEAD-PRESSURE SAFETY CONTROLS	
RANGE SCALE	DIFFERENTIAL SCALE
100 TO 250	20 TO 100
100 TO 400	35 TO 150
150 TO 450	35 TO 150

Fig. 23-19. This table displays the ranges and differentials available in head-pressure safety controls, which make it possible to use the same control with different refrigerants.

ever head pressure changes from unsafe to safe limits. If the condenser fan burns out, the automatic reset control permits the system to cycle on and off.

The automatic reset is most common for commercial applications because it eliminates temporary nuisance shutdowns. These shutdowns usually result from high-heat-load conditions of brief duration. These result in temporary high suction pressure and high head pressure. Head pressure returns to normal when suction pressure is reduced to normal.

The manual reset is preferred by compressor manufacturers, because the control must be manually reset to restore the system to operation. It is assumed that the person resetting the control will investigate and cure the problem that is causing the high head pressure. The manual reset control is often used for air conditioning applications.

Head-pressure safety control settings

To calculate the safety pressure settings for a forced convection (fan-type) condenser, the technician must first know the normal head pressure during the *hottest* day of the year. For example, on a hot summer day, the ambient may reach 100°F (38°C). For R-12 and R-22 systems, the normal head pressure is calculated by adding 30°F to 35°F (17°C to 19°C) to ambient. For R-502 systems, add 20°F to 25°F (11°C to 14°C) to ambient. The lower temperature would be used for a clean condenser; the higher, for a slightly dirty condenser. A temperature-pressure chart can then be used to convert the temperature to pressure. For example, on an R-12 system:

100 + 30 = 130 (181 psig) (clean condenser)
100 + 35 = 135 (194 psig) (slightly dirty condenser)

In this case, the head pressure safety control is set to cut out at a pressure of 215 psig to 225 psig (1482 kPa to 1551 kPa). This extra margin of safety protects the system and prevents nuisance trip-outs. The differential is set for 55 psig to 60 psig (379 kPa to 414 kPa) to permit the system to cool down before automatic reset.

When the condenser becomes very dirty, or if the condenser fan stops running, head pressure will rise rapidly to the cut-out. If the head-pressure safety control is *not*

used, head pressure will continue to rise until the overload stops the compressor. The compressor will cycle on the overload until the head pressure problem is cured.

Water-cooled condensers

Head-pressure safety controls are also used for water-cooled condensers. This safety control is necessary to protect the system if the condenser becomes fouled (dirty), or if water flow stops. The water regulating valve is normally set to maintain a constant head pressure (calculated from an ideal ambient of 70°F, or 21°C).

For R-12 systems, the water regulating valve is set to maintain head pressure of 115 psig (793 kPa). The head pressure safety control is set to cut out at 150 psig (1034 kPa), with a differential of 35 psig (241 kPa).

For R-22 and R-502 water-cooled systems, the water regulating valve is set to maintain a constant head pressure of 200 psig (1379 kPa). The head pressure safety control is set to cut out at 250 psig (1724 kPa), with a differential of about 50 psig (345 kPa).

Wiring connections

Wiring connections for the head-pressure safety control place the switch in series with the primary control. See Fig. 23-20. Safety control switches are usually connected into the same circuit, but act as a secondary control. Sometimes the head pressure safety control is connected in series with the compressor overload. This method shuts the compressor off, but permits the condenser fan to operate. The two methods are equally effective for protecting the compressor.

Dual-pressure motor control

The ***dual-pressure motor control*** is a combination of a low-pressure control and a head-pressure (high-pressure) safety control. See Fig. 23-21. Typically, commercial systems had both a low-pressure control (either primary or safety) and a head-pressure safety control. Manufacturers recognized this and combined the two controls into a single unit.

The dual-pressure control saves time and money because double protection is provided with one control. Wiring connections are simplified because the control has just two terminals. The factory makes the internal connections that permit either switch to disconnect power supply.

Each side of the control operates independently, with its own adjustment scale. If one side of the control becomes nonfunctional, the other side will remain operational. The low-pressure switch opens on falling pressure and the high-pressure switch opens on rising pressure.

The two capillary tubes must be properly connected to the compressor. The smaller bellows is connected to high-pressure and the larger bellows is connected to the low-pressure side. Both sides of the control are fully adjustable by screws that are located directly above each scale.

Some head-pressure controls have only a single *range adjustment* screw, since the differential is factory fixed at 55 psig or 60 psig (379 kPa or 413 kPa). The proper cut-out pressure is selected by the range adjustment screw, while the cut-in is established by the fixed differential.

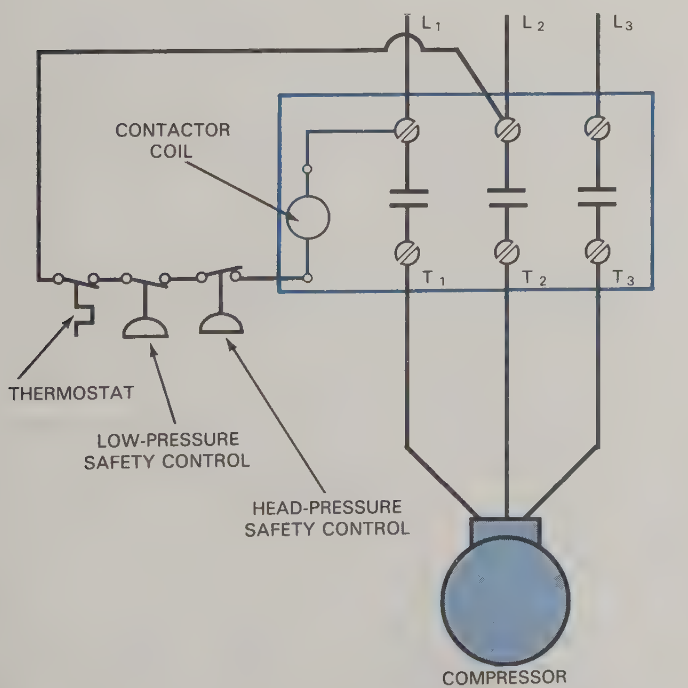


Fig. 23-20. The primary control (a thermostat in this case) and secondary safety controls are usually wired in series with the contactor coil. If any of the switches opens, the power supply to the contactor coil will be cut off.

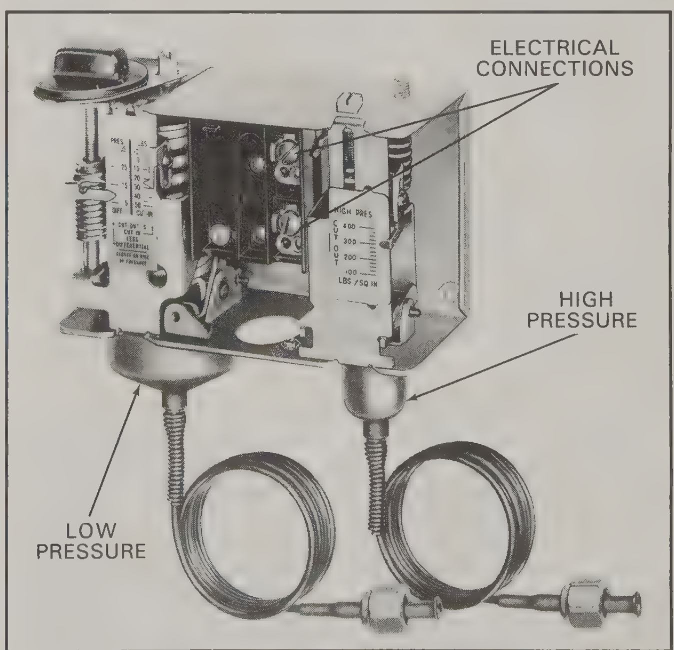


Fig. 23-21. A dual-pressure safety control for both high-pressure and low-pressure protection. On the high-pressure side, the differential is set by the factory, so only a cut-out pressure is set on the scale. The low-pressure control allows setting of both range and differential. (Penn Controls)

This dual-pressure control is available with a manual reset for the high-pressure side.

Condenser fan cycle control

The *fan cycle control* is used to control the condenser fan or fans. When head pressure drops below acceptable limits, the fans are turned off. When pressure returns to normal, however, the control turns the fans back on.

Condenser fan cycling is a common method of maintaining head pressure during cold weather conditions. When the condensing unit is located outdoors, low ambient temperatures result in low head pressure. Low head pressure results in poor system operation.

TEV pressure drop

Proper operation of the thermostatic expansion valve (TEV) depends upon proper pressure drop across the valve. This pressure drop is determined by subtracting normal *suction* pressure from normal *head* pressure. This pressure drop must be maintained or the valve cannot feed refrigerant properly. The compressor will remove refrigerant from the evaporator faster than the valve can feed liquid. Thus, the evaporator pressure becomes too low, and the unit cycles off on the low-pressure control.

Head pressure limits

Head pressure for a system using R-12 should not fall below 100 psig (689 kPa). The minimum head pressure for R-22 is 200 psig (1379 kPa), and R-502 is 180 psig (1241 kPa). Head pressures should be maintained *at or above* these levels to assure proper system operation.

Control contacts

The fan cycle control helps maintain proper head pressure by disconnecting the condenser fan when head pressures fall below an acceptable level. The fan remains off until the head pressure builds up to the cut-in point again. During low ambient, the condenser fan may not run, or may cycle on and off. The contacts on this control must open on falling pressure and close on rising pressure. See Fig. 23-22.

Control connections

The fan cycle control is located at the condensing unit and connected in series with one side of the fan's power supply. Sometimes two condenser fans are controlled by the same switch.

Large condensing units that use multiple fans will *stage* (sequence) individual fans to cycle on or off at different pressures. These controls are set for about a 10 psig (69 kPa) difference. One fan is cycled off at a fixed setpoint; if the pressure continues to drop, another fan turns off. This staging continues until all fans are off, or until the pressure stabilizes. Control settings also turn fans on as head pressure rises.

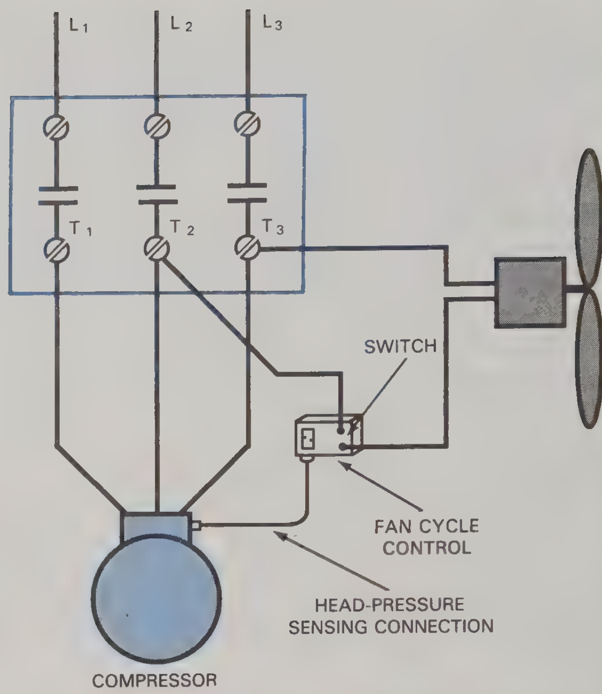


Fig. 23-22. The fan cycle control helps maintain proper head pressure by turning the condenser fan off and on as necessary.

Control settings

R-12 SYSTEMS: Cut-in = 140 psig (965 kPa); Cut-out = 100 psig (689 kPa).

The 40 psig (276 kPa) differential keeps the fan from short-cycling during periods of moderate ambient conditions. A delay exists at each setpoint while the pressure stabilizes. When the switch cuts out at 100 psig, head pressure drops to about 90 psig (621 kPa) because the fan requires time to stop. When head pressure rises to the 140 psig cut-in, time is needed for the fan to achieve full speed, so head pressure rises to about 150 psig (1034 kPa). Therefore, the actual differential is about 60 psi (414 kPa).

R-22 AND R-502 SYSTEMS: Cut-in = 240 psig (1655 kPa); Cut-out = 200 psig (1379 kPa)

The 40 psi differential permits head pressure to reach 190 psig (1310 kPa) after cut-out and 250 psig (1274 kPa) after cut-in. This differential prevents short-cycling of the fan and maintains head pressure within proper limits. The condenser fan must not short-cycle, because the motor will overheat and burn out. However, the fan needs to provide compressor cooling during moderate ambient temperatures.

PUMPDOWN CYCLE

The ***pumpdown cycle*** is very popular for many refrigeration systems which have the condensing unit located outdoors. The pumpdown cycle removes all refrigerant from the low-pressure side of the system prior to shutdown. This prevents liquid slugging and loss of oil from the compressor during start-up.

Principle of operation

The pumpdown cycle has a solenoid valve (electrically operated valve) in the liquid line, with a thermostat controlling power supply to the solenoid coil. See Fig. 23-23. The solenoid valve can be located just before the TEV (evaporator location), or just after the sight glass (condenser location).

Power supply to the solenoid and thermostat is separate from the refrigeration system power supply. The air-sensitive thermostat, located inside the cooled space, controls power to the solenoid coil only. The solenoid valve controls refrigerant flow through the liquid line.

When cooling is required, the thermostat contacts close and energize the solenoid coil. The solenoid valve opens and permits refrigerant flow to the evaporator. The suction pressure rises and a low-pressure control starts the compressor. When the thermostat is satisfied and opens, the solenoid coil is deenergized, allowing the valve to close. Refrigerant flow to the evaporator stops. The compressor continues to pump refrigerant from the evaporator and suction line until the suction pressure reaches the low-pressure control cut-out setting. See Fig. 23-24.

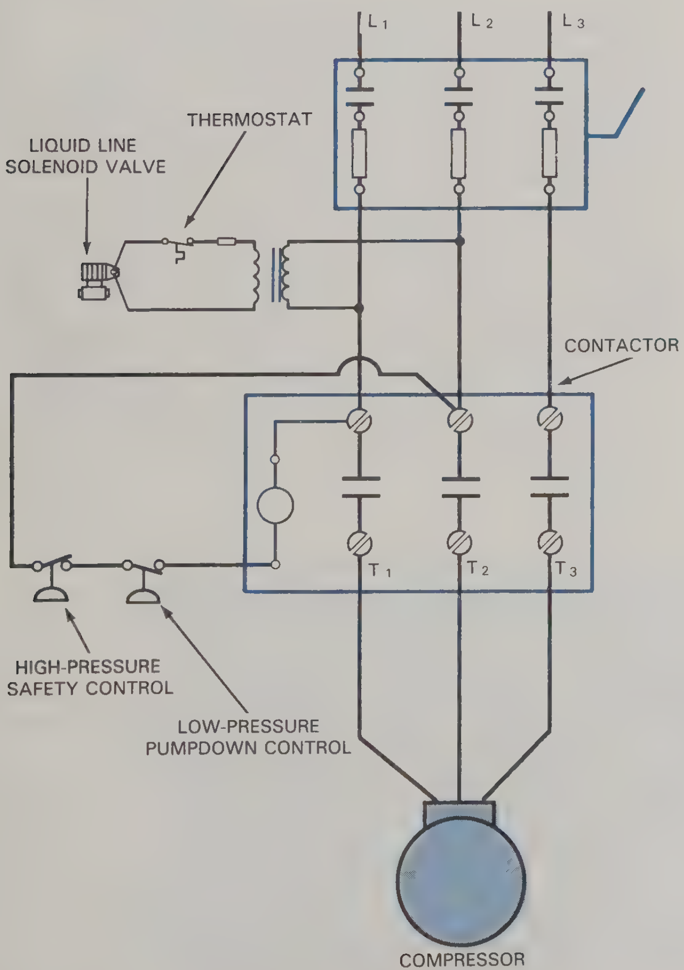


Fig. 23-23. The solenoid valve and the thermostat that controls it have a power supply isolated from the refrigeration system's power supply by a transformer.

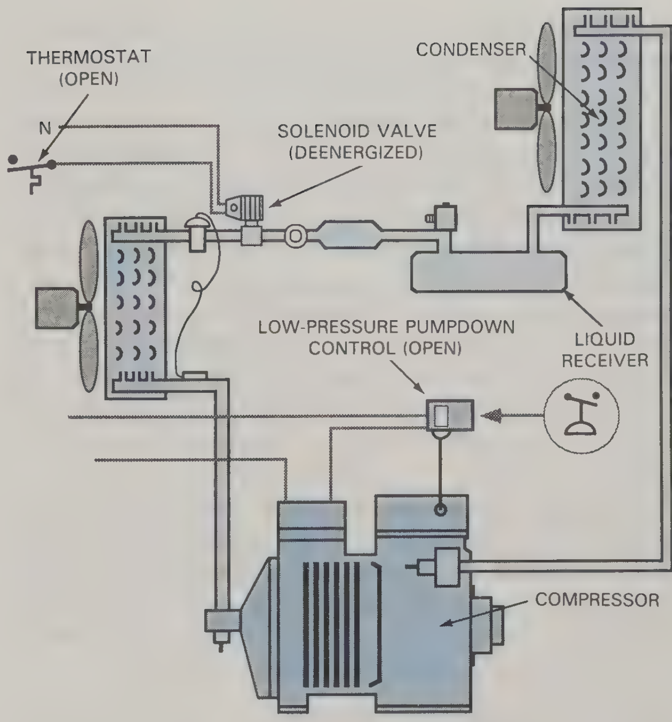


Fig. 23-24. When the thermostat opens, the solenoid valve is de-energized and closes. This shuts off flow to the evaporator through the liquid line. The compressor will continue to operate until the low-pressure pumpdown control switch opens. Refrigerant is stored in the condenser and liquid receiver.

In the pumpdown cycle, the compressor evacuates (removes) all refrigerant from the low-pressure side of the system. The refrigerant is stored in the liquid receiver (and condenser) after each run cycle. Since the receiver and condenser are fully capable of storing this refrigerant, head pressure does not rise.

Advantages of the pumpdown cycle include:

- Preventing liquid migration to the compressor during the off cycle.
- Eliminating high suction pressure at start-up.
- Providing better oil return flow to the compressor crankcase.
- Preventing refrigerant vapor from condensing in the crankcase during cold ambient.

Pumpdown pressure control settings

Pressure control settings for pumpdown are important and vary according to the system. At pumpdown, the cut-out should occur before suction pressure enters a vacuum (about 1 psig to 2 psig, or 7 kPa to 14 kPa). The cut-in pressure setting is more difficult to determine. The cut-in depends upon whether the condensing unit is located indoors or outdoors.

Indoor condensing unit

For indoor condensing units, cut-in is determined from the lowest air temperature (thermostat cut-out). Subtract about 10°F (5°C) from the thermostat cut-in

temperature and convert the result to pressure, using a temperature-pressure chart. This pressure becomes the cut-in on the pressure control.

For example, if the thermostat is set to control temperatures at 32°F to 38°F (0°C to 3°C) degrees, subtract 10°F from 32°F (thermostat cut-out). The result, 22°F (-6°C is converted to pressure (for R-12, 23 psig or 159 kPa). This becomes the cut-in for the pressure control.

Indoor pumpdown system operation. When air temperature reaches 38°F (3°C), the thermostat closes and energizes the solenoid coil. Refrigerant flows to the evaporator. Low-side pressure quickly rises to 23 psig (159 kPa), and the low-pressure control closes. This starts the condensing unit and the system operates for a normal run cycle.

When air temperature is lowered to 32°F (0°C), the thermostat opens and energizes the solenoid. Refrigerant flow to the evaporator stops. The condensing unit continues to operate (pumpdown). Low-side pressure is quickly lowered to 1 or 2 psig; the pressure control opens to stop the condensing unit.

Outdoor pumpdown system

When the condensing unit is located outdoors, low ambient temperatures greatly affect the cut-in setting. During the off cycle, all refrigerant is stored in the liquid receiver (outdoors) and becomes the same temperature as outdoor ambient. Cut-in is determined from the coldest anticipated outdoor ambient. The temperature-pressure in the cold receiver cannot be lower than the cut-in of the pressure control.

To overcome cold ambient problems, the cut-in setpoint *must* be equal to the coldest likely outdoor temperature. Failure to abide by this rule will result in nuisance service calls when outdoor temperatures drop to low levels. The thermostat will energize the solenoid valve, but the compressor will not run because *refrigerant pressure* is lower than the control cut-in. Fig. 23-25 is a table of typical pressure control settings when outdoor ambient is below system operating temperatures.

Outdoor pumpdown cut-out. The pressure control cut-out normally occurs before the systems enters a vacuum. This is not always possible when outdoor ambient is low, however. The technician must adjust the control for cold ambient conditions. As shown in Fig. 23-25, pumpdown systems using R-12 will frequently pull into a vacuum. The lowest recommended cut-out for R-502 is 3 in. Hg.

Pumpdown differential. The differential for pumpdown cycles must prevent short-cycling after the initial cut-out. When the solenoid valve closes, the compressor rapidly removes refrigerant and reaches the cut-out point. Some gas remains in the low-pressure side. After shutdown, this gas residue causes low-side pressure to rise to the cut-in setpoint. The compressor cycles briefly until the low-side pressure is reduced to the cut-out. One brief re-cycle is not unusual and serves to remove residue refrigerant. Several short cycles before complete shutdown indicates a short differential.

Troubleshooting

Recycling after shutdown is caused by a system that is low on refrigerant, a differential set too close, a leaking solenoid valve seat, or leaking compressor discharge valves. These problems can be isolated, identified, and corrected, using the following procedures:

Pumpdown system low on refrigerant. Install gauge manifold on compressor service valves and remove cover from low-pressure control. Check control operation with a voltage tester or by observing the mechanical action of the control as it opens and closes.

Check operating pressures and the sight glass. The sight glass may show some bubbles immediately after start-up, but the bubbles should quickly disappear and the glass should indicate a full system. Excessive and continuous bubbles in the sight glass (even when compressor is off), along with low pressures, indicate that the system is low on refrigerant. The leak must be located and repaired, and the system recharged to full capacity.

CONTROL SETTINGS FOR COLD AMBIENT						
COLDEST AMBIENT	R-12		R-22		R-502	
	CUT-IN	CUT-OUT	CUT-IN	CUT-OUT	CUT-IN	CUT-OUT
+30	25	1	40	1	40	1
+20	18	1	30	1	40	1
+10	13	0	25	1	35	1
0	5	5''	20	0	25	0
-10	3	8''	15	0	20	0
-20	0	10''	8	0	13	0
-30	5''	15''	4	6''	9	2''

Fig. 23-25. Table of pressure control settings for cold ambient. Ambient temperatures are in °F and cut-in/cut-out pressures in psig (except for *vacuum* readings, marked with '' for in. Hg).

Check magnetism of solenoid coil with small screwdriver to determine if solenoid is energized. If the solenoid is not energized, check power supply to thermostat and determine if thermostat contacts are open or closed. Turning the thermostat to a warmer setting should energize the solenoid valve.

Differential set too close. Remove cover from the low-pressure control and check scale settings against pressures observed on gauge manifold. The control scale can be misleading or inaccurate, so adjustments should always be performed using the gauge manifold. Inaccurate or improper settings should be corrected to provide proper system operation.

Leaking compressor discharge valve reeds. Compressor discharge valve reeds that are leaking or broken are easily discovered by following this procedure:

1. Install the gauge manifold on the compressor service valves.
2. Frontseat the suction service valve to prevent any refrigerant from entering the compressor.
3. Force compressor to run by using a jumper cord to bypass the low-pressure control.
4. Allow compressor to pull good vacuum (20 in. Hg to 25 in. Hg).
5. Stop the compressor and observe the low-side gauge for rapid loss of vacuum. If it occurs, replace the valve plate.

Compressor discharge valve reeds generally show slight leakage, but a *rapid* loss of vacuum indicates faulty compressor discharge reeds. The compressor discharge valve reeds are a division point between the high-pressure and low-pressure sides of the system. If they are broken or not seated properly, they will permit high pressure to leak back into the low-pressure side. This problem can be repaired in the field by the service technician using a valve plate replacement kit, which contains new valve reeds.

Leaking pumpdown solenoid valve. This problem is rare, but is indicated by regular short-cycling of the compressor after pumpdown due to refrigerant leaking into the low-pressure side. The refrigerant leakage may result for leaking compressor discharge valve reeds, or a leaking solenoid valve seat.

The problem is isolated by first checking the discharge valve reeds, as previously described. If discharge valve reeds are functioning properly (no loss of vacuum), the problem *must* the solenoid valve.

Sometimes a Schrader valve is available in the suction line for checking suction pressures. If so, the solenoid valve seat can be checked by using this procedure:

1. Connect the compound gauge to the Schrader valve.
2. Force the compressor to pull a good vacuum, then frontseat the suction service valve. Stop the compressor. The suction service valve will prevent return pressure from the compressor.
3. Observe the compound gauge. It will reveal if low-side pressure remains in a vacuum or rises to the cut-in point. If pressure rises, the solenoid valve seat is leaking. The defective valve must be replaced.

OIL PRESSURE SAFETY CONTROL

The ***oil pressure safety control*** is used to protect the compressor when lubrication problems occur. Many compressor failures caused by lack of lubrication could have been prevented by using an oil pressure safety control. Warranties on compressors using an oil pump specify that the unit *must* be equipped with an oil pressure safety control.

Loss of compressor lubrication can cause a variety of system problems:

- Shortage of oil in the system.
- Oil remaining in the evaporator (called ***logging***) due to low refrigerant velocity.
- Shortage of refrigerant.
- Refrigerant migration or floodback to the crankcase.
- Oil pump failure.
- Faulty refrigerant control devices.
- Short cycling.

Regardless of cause, the compressor must be protected against loss of oil pressure. Permitting the compressor to operate without proper lubrication will result in certain failure from broken piston rods, locked bearings, or similar causes. The oil pressure safety control is designed to stop the compressor before such damage occurs. It also warns the technician that an oil problem exists. An oil pressure safety control is standard equipment on any compressor equipped with an oil pump. See Fig. 23-26.

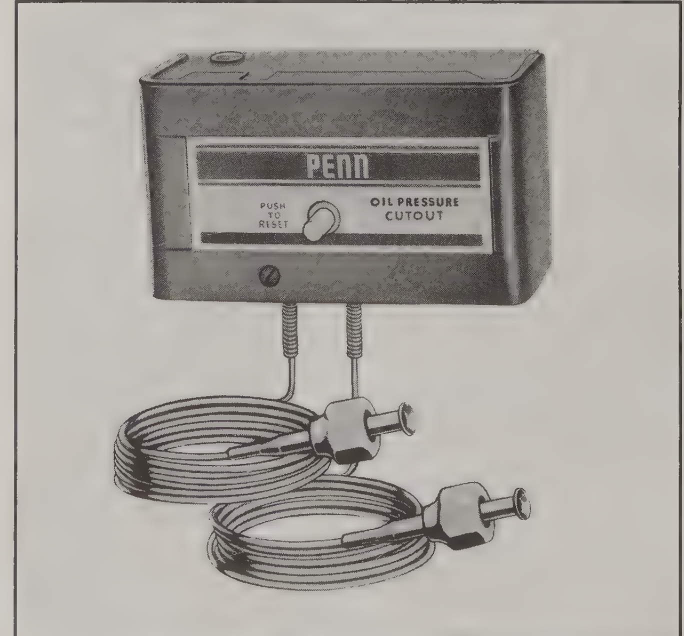


Fig. 23-26. The oil pressure safety control prevents compressor failures caused by loss of lubrication. It will stop the compressor if oil pressure drops below a safe level. The control is not adjustable. (Penn Controls)

Control connections

The oil pressure safety control is unlike any other type of control. It has two switches, two pressure-sensing bellows, and two capillary tubes for connection to the compressor. One capillary tube and bellows is tagged "low" and connected to the compressor crankcase (low-side pressure). The other capillary tube is tagged "oil" and connected to the oil pump. The tubes are tagged at the factory to prevent confusion when making these connections.

Two capillary tubes are needed because the control operates on the *difference* between crankcase pressure and oil pump pressure. The oil pump produces a pressure that is higher than the low-side, or crankcase, pressure. This pressure difference is called ***net oil pressure.*** Net oil pump pressure is obtained by subtracting crankcase pressure from oil pump pressure. (Oil pump pressure *never* falls below crankcase pressure, so it is necessary to subtract crankcase pressure from oil pump pressure to obtain net oil pressure.)

Most oil pumps are equipped with a tee fitting for making connections. The capillary tube (tagged "oil") from the safety control is connected to the #2 opening on the tee. The remaining tee branch (#3 opening) is fitted with a Schrader valve for obtaining oil pump pressure readings during operation. Two compound gauges are needed to check net oil pressure. One gauge is used to obtain low-side pressure at the suction service valve, and the other is connected to the oil pump Schrader valve to read oil pump pressure. The difference between the two pressure readings is net oil pressure.

Principle of operation. The oil pressure safety control has two normally closed switches. One is used to control a small heater. The contacts controlling power to the heater are tagged T_1 and T_2. Operation of the heater causes a secondary (bimetallic) switch to open. The bimetallic switch contacts are tagged L and M. This switch is connected in series with the primary control and the contactor coil. Fig. 23-27 shows a typical connection for an oil pressure safety control on a three-phase motor-compressor.

The two pressure-sensing bellows operate the switch at T_1 and T_2, which controls power supply to the small heater. At start-up, power is supplied to both the compressor and the heater. When net oil pressure reaches 12 psig (83kPa), the heater switch opens. This cuts off the power supply to the heater, but the compressor continues to run. During the run cycle, if net oil pressure drops to 9 psig (62 kPa), the switch will close and restore power to the heater.

If net oil pressure fails to achieve 12 psig after start-up (it is much higher in normal operation), the switch at T_1 and T_2 remains closed and the heater gets hot. It requires about 120 seconds (two minutes) for the heater to produce enough heat to warp open the bimetallic switch connected between L and M. When the bimetal-

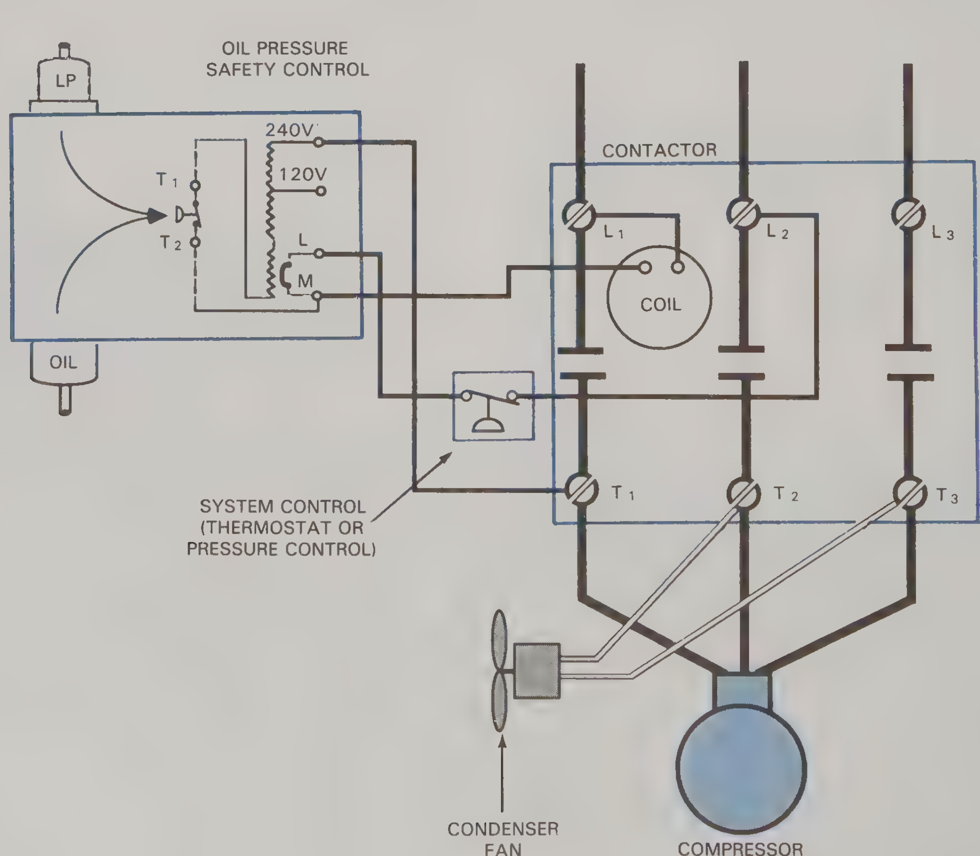


Fig. 23-27. Typical electrical connections for an oil pressure safety control. The bimetallic switch inside the control is connected at terminals L and M.

lic switch opens, power supply to the contactor coil is interrupted and the compressor stops. All oil pressure safety controls must be manually reset when they open.

Control heater. The heater provides a time delay required for the pump to establish oil pressure after start-up. It also prevents nuisance shutdowns due to brief shortages of oil pressure during the run cycle. The compressor is permitted to operate without proper lubrication for the amount of time required for the heater to get hot. The heater and bimetallic switch are carefully selected at the factory to provide a specific time delay. Oil pressure safety controls are available with time delays of 60 seconds, 90 seconds, or 120 seconds. This time delay is nonadjustable; each compressor manufacturer specifies which delay is used on its product. The 120-second control is most common.

To provide for dual-voltage operation, there are two resistance heaters located inside each control. Only one is used when connecting the control for 120V operation. The two resistance heaters are automatically connected in series when using 240V operation. As shown in Fig. 23-28, these two terminals are clearly identified for selecting proper voltage connections in the field.

Wiring connections

Power supply to the resistance heaters *must* be obtained from the bottom of the contactor. This prevents the heater from being energized during the off cycle. All other power supply connections are obtained from the top of the contactor.

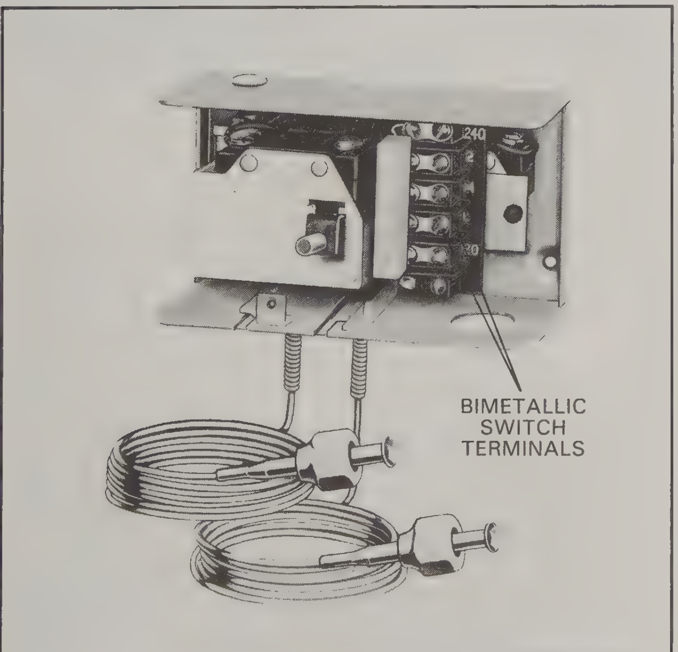


Fig. 23-28. Oil pressure safety control with cover removed to show electrical terminals. Terminals L and M are used to connect the control's bimetallic switch in series with the contactor coil. Note the dual-voltage provision, with 120V and 240V terminals. (Penn Controls)

Heater connections. Power supply to the heater is performed by connecting a wire from T_1 on the contactor to 240 on the control. The other side of the heater obtains its power from the connections at the bimetallic switch. When the compressor contactor is closed, a circuit is made from T_1 on the contactor to the 240V resistor connection, through the resistors, to the heater. From the heater, power travels through the switch at T_1 and T_2, through the bimetal contacts at L and M, through the low-pressure control, to L_2 at the top of the contactor.

Contactor coil connections. One side of the contactor coil is connected to L_1 on the contactor. From the coil, current travels to M on the bimetallic switch contacts, through the switch to L, and picks up the power supply traveling to the low-pressure control and up to L_1. The compressor cannot operate unless both the bimetallic switch at L-M and the low-pressure switch are closed. At start-up, if the net oil pressure does not build up sufficiently to take the resistance heater out of the circuit within 120 seconds, the heater will cause the bimetallic switch to open. This interrupts power to the contactor coil and stops the compressor.

Troubleshooting

To check the pressure settings on the control, pump the system down by frontseating the liquid receiver service valve and forcing the compressor to run. When a vacuum of 10 in. Hg to 15 in. Hg is obtained, shut off the compressor and briefly crack open the liquid receiver service valve to eliminate the vacuum. Disconnect both capillary tubes from the compressor. Leave the low-pressure capillary tube open to the atmosphere to sense "zero" pressure.

Connect the middle hose from the gauge manifold to a cylinder of refrigerant. Connect the low-pressure hose to the "oil" capillary tube. Open the manifold hand valve until the low-pressure gauge indicates a pressure between 20 psig and 60 psig (138 kPa 414 kPa). Check for continuity between T_1 and T_2. The switch should be open.

Bleed the pressure off slowly and observe the gauge. The switch should close at about 9 psig (62 kPa). Slowly raise the pressure again until the switch opens. This should occur at a pressure of between 12 psig and 14 psig (83 kPa and 97 kPa). The switch will make a "click" sound each time it opens or closes. If the control does not open and close within the specified pressure range, it should be replaced.

SUMMARY

Motor controls serve many functions in the refrigeration system. They provide automatic control of system operation (primary control) and protection from possible malfunctions (safety controls). Motor controls

can be temperature-sensitive (thermostats), or pressure-sensitive (pressure controls).

This chapter explained the operation, application, wiring connections, and troubleshooting procedures for each motor control. Domestic controls are different from commercial types, but their operation is similar. The technician must be able to install and properly adjust the various types of controls. System problems are often pinpointed by these controls, so the technician must be able to troubleshoot and repair controls and associated devices.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Name two types of primary motor controls.
2. The setpoint that causes the control contacts to close is called the ________.
3. The span between cut-in and cut-out temperatures or pressures is called ________.
4. Primary controls perform their job by connecting or disconnecting the ________ to the contactor coil.
5. The ________ screw changes cut-in and cut-out equally.
6. The differential adjustment screw changes only the ________.
7. On a three-phase system, is the thermostat switch connected in series or in parallel with the contactor coil?
8. When setting the cut-out, how much pressure (in psig) must be subtracted to allow for pressure drop?
9. The low-pressure safety control becomes necessary when a ________ is used as the primary control.
10. Why are low-pressure safety controls used on air conditioning systems?
11. The low-side pressure on air conditioning should not fall below ________ psig.
12. In air conditioning, the temperature of the AIR OFF should be 10°F above the temperature of the ________.
13. What causes the low-pressure safety control switch to open?
14. True or false? The head pressure safety control switch is connected in parallel with the primary control.
15. The fan cycle control is used to ________.
16. On a pumpdown cycle, what does the cooled-space thermostat control?
17. What is the purpose of the low-pressure control on a pumpdown cycle?
18. The oil pressure safety control operates on ________ oil pressure.
19. On the oil pressure safety control, the heater is controlled by a pressure switch located between terminals ________.
20. Are oil pressure safety controls reset automatically or manually after they "trip" due to low oil pressure?

Chapter 24

DEFROST CYCLES

After studying this chapter, you will be able to:
- *Identify various domestic and commercial defrost timeclocks.*
- *Describe the five types of defrost cycles.*
- *Install and properly adjust defrost timeclocks.*
- *Connect and troubleshoot defrost terminator thermostats.*
- *Explain operation of, and make necessary adjustments to, domestic and commercial defrost systems.*
- *Adjust temperature and pressure termination.*

NEW WORDS

atmospheric air
automatic off-time defrost
capacity control
condensate pan
condense
defrost cycle
defrost terminator thermostat
dehumidifier
dewpoint
electric defrost
energy efficiency ratio (EER)
evaporator fan delay thermostat
fail-safe setting
freeze-up
hot gas defrost
humidistat
humidity
initiate
mullion heaters
off-cycle defrost
relative humidity
reverse-air defrost cycle
reversing relay
saturated
suction accumulator
temperature-terminated timeclock
terminate
time-initiated/pressure-terminated timeclock
time-initiated/time-terminated clock
water vapor

PHYSICAL PROPERTIES OF AIR

Most refrigeration systems are designed to cool air, which is in turn used to cool a product or space. The physical properties of ordinary air can become complicated. These physical properties must be controlled or serious problems will develop in the refrigeration system.

Temperature and moisture content (humidity) of atmospheric air are important factors, but filtering (cleaning) and circulation (movement) are also important. Automatic control of temperature, humidity, filtering, and circulation are considered when designing refrigeration and air conditioning systems. This chapter explains the various properties of air and how systems are designed to control air problems.

Atmospheric air is a mixture of various gases and ***water vapor*** (moisture). Air has weight, density, temperature, and specific heat. More energy is required to move cold air because cold air is heavier than warm air. Density of air varies with atmospheric pressure and the amount of water vapor in it. At sea level, one pound of air occupies a space of about 14 cu. ft. and has a density of .0725 lb./cu. ft. (pounds per cubic foot). The specific heat of *dry* air at sea level is .24 Btu/lb.; the specific heat of *moist* air increases with the moisture content.

HUMIDITY

Humidity is a term used to describe the moisture content of air. This humidity, or water vapor, is invisible. The amount of moisture that air will hold depends upon the temperature, and has a direct influence upon human comfort. For example, dry air will cause rapid evaporation of moisture from the human body. A person may feel cold in moderate temperature conditions, because of the evaporation of skin moisture. Moist

(very humid) air will not absorb much moisture, so a person may feel uncomfortable due to poor evaporation.

Warm, moisture-laden air will release much of its moisture when it touches a cold surface. The air temperature near the cold surface is lowered, causing the moisture to ***condense*** (change to a liquid state) on the surface. Water dripping from cold pipes is caused by condensation of moisture from the air onto the pipes. Insulation on the pipe will prevent condensation by keeping air from contacting the pipe. This explains why cold suction lines on refrigeration equipment are insulated. If the suction line temperature is below the freezing point of water, condensation will freeze on the lines. This frost or ice is easily confused with frost formed in liquid floodback situations.

Relative humidity

Relative humidity is the term used to describe the amount of moisture held by one cubic foot of air. This moisture content is then compared to the amount of moisture the air *would* hold if *saturated* (full). Air that is holding half the moisture it is *capable* of holding has a relative humidity of 50 percent. The relative humidity of *saturated* air is 100 percent. Low relative humidity indicates dry air, high relative humidity indicates moist air. Warm air holds more moisture than cold air. As air temperature is lowered, relative humidity goes up. When the relative humidity reaches 100%, further reduction of temperature causes moisture to be released (condensed out).

Dewpoint

Dewpoint is a term used to describe the point at which the air becomes saturated (holds all the moisture it is capable of holding) for a given temperature. Dewpoint is simply another way of describing 100% relative humidity.

Dehumidifiers

A ***dehumidifier*** is a refrigeration system designed specifically to remove moisture from air without affecting air temperature. See Fig. 24-1. A dehumidifier is very useful for "drying out" a damp basement. The evaporator is usually a coil of tubing without fins, and is placed immediately in front of the condenser. The fan draws air across the evaporator tubing and then across the condenser.

When humid air contacts the cold evaporator coil, moisture condenses on the tubing and runs down to a catch pan. The catch pan is drained into a pail or similar vessel. It also may be routed to a hose leading to a floor drain. Air flowing across the evaporator will be cooled and give up moisture, then flow across the condenser and pick up heat. This arrangement permits the air temperature to remain unchanged, since only moisture is removed.

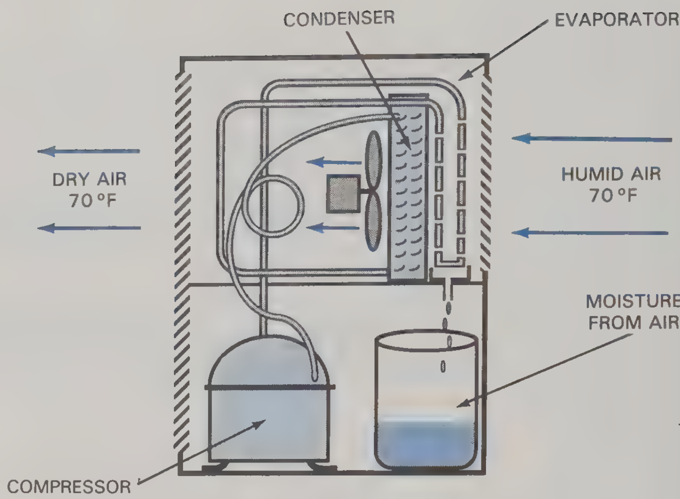


Fig. 24-1. A dehumidifier removes moisture from air without affecting air temperature.

A special ***humidistat*** (moisture-sensitive switch) is used to control system operation. The humidistat sensing element is a nylon ribbon that stretches and contracts according to humidity. The refrigerant temperature-pressure relationship must be maintained to keep evaporator temperature above the freezing point of water (32°F or 0°C). Moisture must not be allowed to freeze on the evaporator.

HUMIDITY AND AIR CONDITIONING

All air conditioning systems act as dehumidifiers, because the evaporator lowers air temperature to below the dewpoint. Moisture collects on the cold evaporator and drips into a catch pan, which is connected to a floor drain. The process of removing moisture from air will add a significant heat load on the system. Moisture must be removed before air temperature can be lowered. High humidity can prevent an air conditioner from lowering temperature. Humidity removal is a latent heat load. Latent heat (moisture) must be removed before sensible heat (temperature) can be lowered.

The temperature of an air conditioning evaporator must be maintained above the freezing point of water. This prevents moisture from freezing on the evaporator. Evaporator temperature is maintained by controlling suction pressure. Airflow across the evaporator (heat load) is limited by blower and duct sizes. During periods of high sensible and latent heat loads (high air temperature with high humidity), these limits may prevent the system from performing properly.

Many residential air conditioning systems are sized for operation under normal conditions, but fail to perform properly during periods of peak loads involving high temperature with high humidity. Such systems are undersized for operation during very hot and moist summer days. Oversizing to compensate for extreme conditions, however, can cause the system to short cycle during normal conditions.

Most commercial air conditioning systems are sized to operate properly under peak loads, but provide ***capacity control*** for use under low load conditions. Capacity control is attained by using unloaders or bypass valves, or by cycling multiple compressors.

DEFROST SYSTEMS

If the evaporator temperature is lower than 32°F (0°C), the freezing point of water, moisture will freeze on the evaporator surface. The accumulation of frost and ice will restrict proper airflow, and will act as an insulator, preventing heat transfer. An evaporator full of frost and ice cannot remove heat from the air because the air molecules cannot touch the evaporator surface. A ***defrost cycle*** is necessary to remove frozen moisture from the evaporator and restore it to full efficiency.

Air conditioning systems do not require a defrost cycle because evaporator temperature is maintained above 32°F (0°C). Refrigeration systems often require a defrost cycle, however, because they have an evaporator temperature that is below freezing.

Automatic defrost is usually controlled by a special timeclock that has two or more switches. The timer and its switches will automatically turn off certain system components (the compressor and evaporator fan), and turn on other components (the evaporator electric heater). When proper time has elapsed, the timer will reverse the switches and restore the system to normal operation.

Various types of defrost timeclocks are available to meet any specific need. Timer selection is determined by the type of defrost cycle.

TYPES OF DEFROST CYCLES

Different methods are used to clear the evaporator of frost accumulation. Domestic and commercial defrost systems differ, but make use of similar principles. There are five basic types of automatic defrost systems:

- **Off-cycle defrost.** This is a commercial system that automatically defrosts itself during each off cycle. The thermostat settings (or the low pressure control) prevent the system from operating until evaporator temperature has reached 38°F (3°C).
- **Off-time defrost.** This commercial system uses a timeclock to turn off the condensing unit for about two hours (usually at night). The evaporator fan runs continuously, with airflow helping to melt any frost or ice that accumulated during the daily run cycles.
- **Electric defrost.** This defrost method is frequently used on both domestic and commercial systems. The system is controlled by a timeclock that automatically turns off the condensing unit, stops the evaporator fan, and turns on electric resistance heaters that are fastened to the evaporator. This timeclock can perform several defrost cycles each day.
- **Hot gas defrost.** Hot gas defrost is primarily a commercial system, but some older domestic refrigerators also use it. Gas is taken from the hot gas discharge line and piped directly to the evaporator inlet. A solenoid valve is located in this bypass line and controlled by a timeclock. At defrost time, the clock stops the evaporator fan and energizes the bypass solenoid valve. The condensing unit operates, but hot gas bypasses the condenser and travels directly to the evaporator inlet, providing the necessary heat to melt frost on the evaporator.
- **Reverse-air defrost.** This is a recently developed energy-saving commercial defrost system used for defrosting multi-deck frozen food display cases in supermarkets. A timeclock turns the condensing unit off and activates a special relay that reverses rotation of the evaporator fans. This reverse rotation draws warm ambient air into the canopy air ducts of the display cases. The warm air is blown through the evaporator to melt frost, then discharged back into the store through the cases' lower air ducts.

Defrost timeclocks

Defrost timeclocks can be divided into domestic and commercial types. See Fig. 24-2. Domestic timeclocks are sealed and nonadjustable. Commercial timeclocks are accessible and fully adjustable. All timeclocks have an electric motor that turns gears for opening and closing electrical switches.

MANUAL DOMESTIC DEFROST SYSTEMS

Many domestic refrigerators do not have automatic defrost. These systems must be manually defrosted on

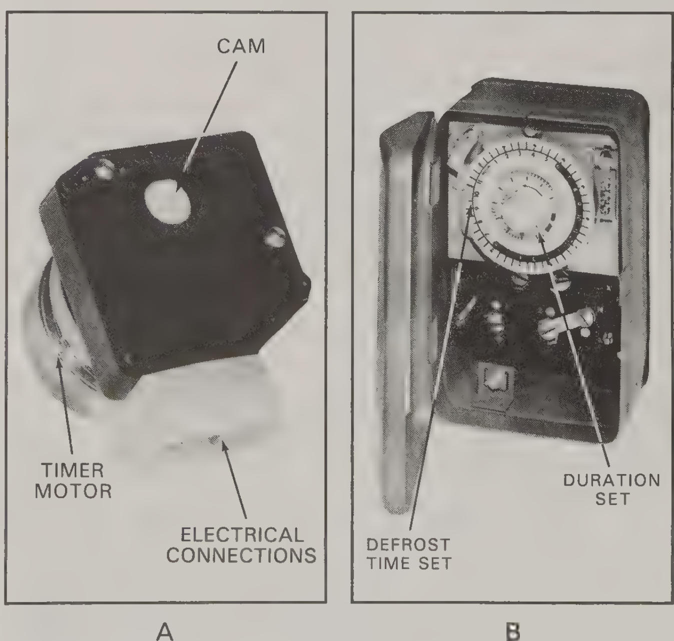


Fig. 24-2. Defrost timeclocks. A–Domestic timeclocks are not adjustable. B–Commercial timeclocks permit setting of the starting time and duration of each defrost cycle. (Paragon Electric Co.)

a regular basis. Defrost is best accomplished by using this method:

1. Turn off the thermostat or unplug the appliance.
2. Empty the freezer section of product.
3. Place containers of hot water in the freezer section. Heat from the water will quickly soften the frost and ice. Usually, large chunks of frozen material can be removed by hand.
4. Restart the system immediately after frost is removed from the freezer section.
5. Replace product in the freezer section.

IMPORTANT: Never use a sharp instrument for prying or chipping frost from a freezer compartment. It is very easy to poke a hole in the thin aluminum evaporator. Repairing holes in the evaporator is difficult and expensive.

AUTOMATIC DOMESTIC DEFROST SYSTEMS

Domestic refrigerator-freezer systems that have automatic defrost are sometimes called "frost-free." The ***electric defrost*** system automatically performs the defrost and disposes of resulting water. The system is quite simple, but differs from commercial systems.

Domestic timeclocks

All automatic defrost (frost-free) refrigerator-freezers use a defrost timeclock to regulate frequency and duration of each defrost cycle. This clock is usually located behind the toe plate grille at the bottom front of the unit. Some are located in the rear compressor section, or inside the refrigerator with the thermostat and light bulb. See Fig. 24-3.

The timer consists of a motor, gear assembly, switches, and a rotating cam. The camshaft is geared to the motor so that it will complete a certain number of revolutions per day. Revolutions per day will vary according to manufacturer's specifications. There may be four (one every 6 hours), three (one every 8 hours), or two (one every 12 hours). At the end of each revolution, the switches are activated and the system enters a defrost cycle. Duration (length) of the defrost cycle varies from 10 to 35 minutes. Average defrost length is 28 to 30 minutes.

Domestic defrost timeclocks are a critical element in proper system operation, but failure is rather common. Be sure to obtain an exact replacement. Defrost cycle frequency and duration are determined by the equipment manufacturer, and are nonadjustable.

The front of the timer contains a plastic screwhead connected directly to the timer camshaft. This screwhead is designed for clockwise rotation by a screwdriver, and prevents counter-clockwise movement. See Fig. 24-4. When turning the cam with a screwdriver, a sharp "click" will be heard at the beginning and end of the defrost cycle.

Most domestic timeclocks have four terminals, numbered 1, 2, 3, and 4. The power supply is normally connected to terminals 1 and 3 because these two terminals supply power to the clock motor. Terminal 1 also supplies power to the switches. The normally closed contacts are between terminals 1 and 2, and the normally open contacts are between terminals 1 and 4. During a defrost cycle, the closed switch will open and the open switch will close. See Fig. 24-5.

The switches and terminal numbers described here are the most common, but some exceptions can be found.

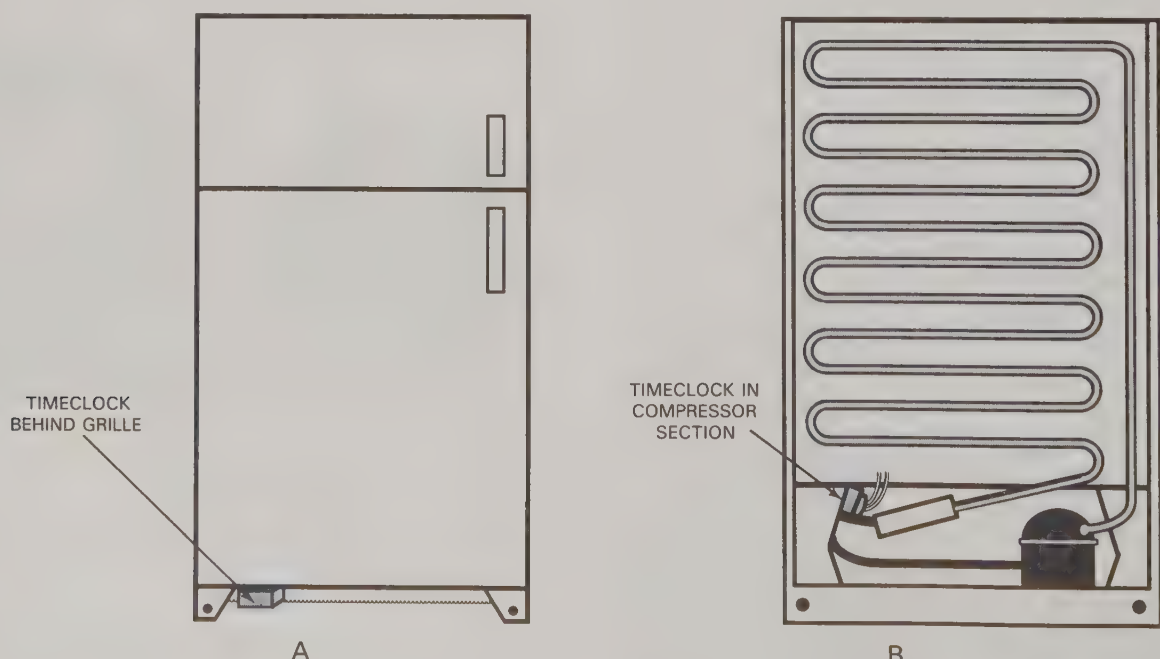


Fig. 24-3. Typical front and rear locations of defrost timeclock on domestic refrigerators. A–At front, behind toe plate grille. B–At rear, in the compressor section.

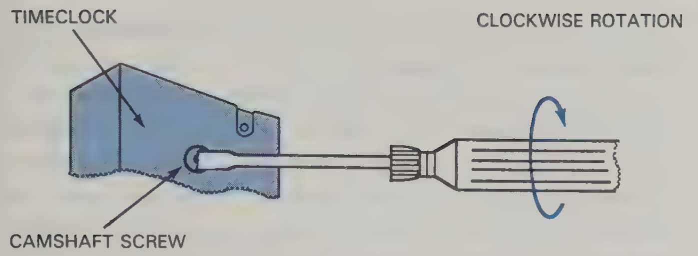


Fig. 24-4. When camshaft screw is turned clockwise, a distinct ''click'' will be heard each time the defrost cycle switch opens or closes.

For example, General Electric and Hotpoint use a timeclock with the normally closed switch located between terminals 1 and 4, and the normally open switch is located between terminals 1 and 2. When making a replacement, always check the appliance schematic against the new clock for proper terminal numbers and arrangement.

Domestic electric defrost cycle

Power supply (hot leg) to the condensing unit is obtained from the timeclock at terminal 2, because this is the normally closed switch. The other side of power supply (neutral) can be obtained at terminal 3 on the clock, but can also be obtained from another location. It is standard practice to place all switches in the *hot* wire and never disconnect the neutral (white) wire. This procedure makes it possible to tap into the neutral (white) wire at any location to obtain that side of power supply.

The evaporator fan also obtains power from terminal 2. During a defrost cycle, power supply to terminal 2 is open and stops operation of the condensing unit and evaporator fan. See Fig. 24-6.

One or more electric resistance heaters is attached to the evaporator; the heater(s) are energized only during the defrost cycle. See Fig. 24-7. Control of the defrost heater is accomplished by obtaining power supply from the clock at terminal 4.

Defrost terminator thermostat. If the frost accumulation on the evaporator is less than normal, defrosting may be completed before the time set on the clock expires. This situation could prove dangerous, since the defrost heaters could become too hot and cause severe damage. A ***defrost terminator thermostat*** is used to disconnect the heater when the evaporator temperature reaches about 50°F (10°C). The terminator thermostat is a bimetallic disc inside a sealed container that looks somewhat like an overload. Two wires are provided for

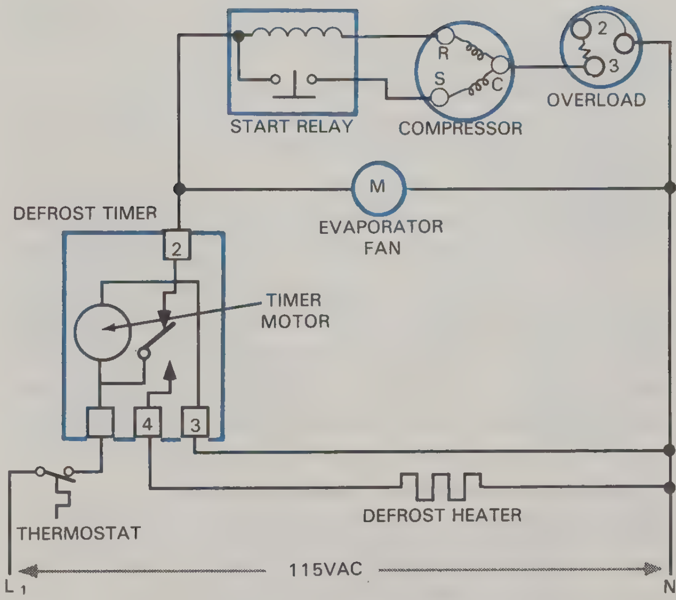


Fig. 24-6. Typical schematic showing how the timeclock controls operation of a refrigeration system. The circuit to the motor-compressor and evaporator fan is through a normally closed switch. The defrost heater is connected to the normally open switch.

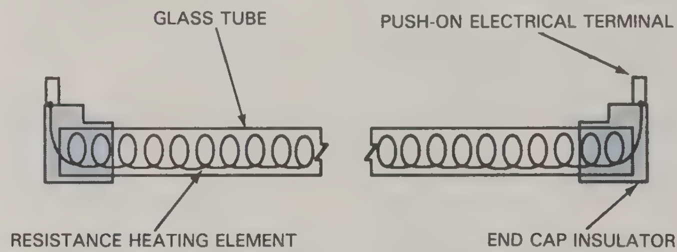


Fig. 24-7. Cutaway view of a defrost heater typically used in domestic applications.

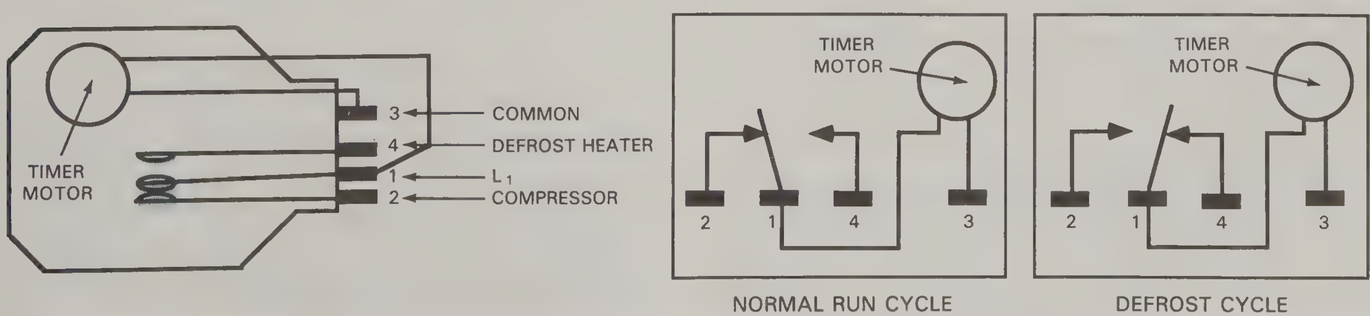


Fig. 24-5. The timer causes switches to change position for the defrost cycle. As shown, the switch is normally closed between terminals 1 and 2 to supply power to the compressor. The defrost cycle causes the contact to open between terminal 1 and terminal 2, and close from terminal 1 to terminal 4. This cuts off the power supply to the compressor, and energizes the defrost heater.

making electrical connections. The defrost terminator thermostat is connected in series with power supply from the clock to the defrost heater, Fig. 24-8.

The defrost terminator thermostat is clamped onto the evaporator tubing, or mounted very close to the evaporator. Once all frost has been removed, evaporator temperature rises quickly. When evaporator temperature reaches about 50°F, the bimetallic disc inside the thermostat warps and opens its contacts. This cuts off the power supply to the defrost heater. The system must wait for the defrost timeclock to finish its cycle before normal operation resumes. When evaporator temperature drops to about 30°F (-1°C), the bimetallic disc contacts will close, ready for the next defrost cycle.

Domestic thermostat connections. Older refrigerators connected the thermostat in series with one side of power to the condensing unit, but *after* the timeclock. The timer motor operated continuously and the evaporator fan shut off only during a defrost cycle. To accomplish energy conservation and increase the refrigerator's ***energy efficiency ratio (EER),*** newer refrigerators place the thermostat in series with power supply to the timeclock. The timeclock, condensing unit, and evaporator fan can operate only during a run cycle, when the thermostat is closed. The defrost cycle is based upon accumulated running time.

This difference in wiring connections results in some energy savings, because the clock and evaporator fan are also stopped during the off cycle. The thermostat determines running time ("on" cycle) and is located inside the refrigerator section. The refrigerator door is opened more frequently than the freezer door. This permits heat to enter and causes the thermostat switch to close. The refrigerator section normally receives its cold air from an evaporator located inside the freezer section. A small air duct controls air flowing from the freezer to the refrigerator section.

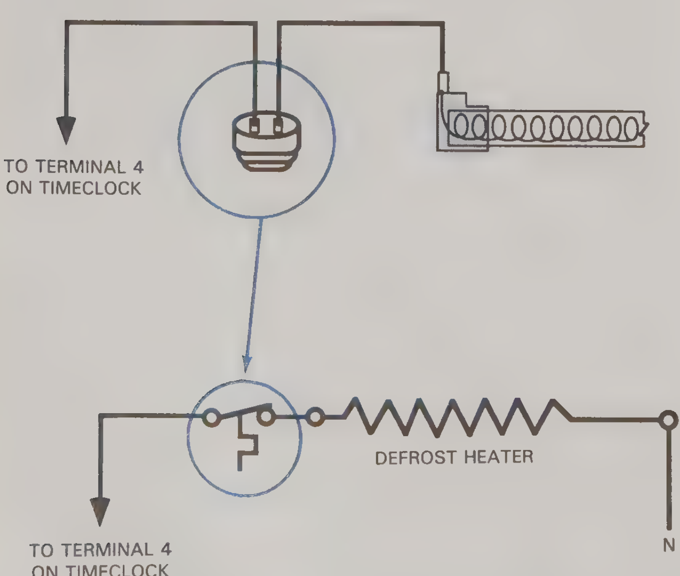


Fig. 24-8. A defrost terminator thermostat is connected in series with the timeclock and the defrost heater.

Defrost water disposal. All automatic defrost systems require a ***condensate pan*** under the evaporator to catch the resulting defrost water. Water travels from the condensate pan through a drain line to a catch pan located in the compressor compartment. Sometimes the condensate pan is heated during defrost to keep the water from freezing in the pan instead of traveling down the drain.

On domestic systems, this condensate water is drained to another catch pan located within the compressor compartment. This removable catch pan rests upon a metal plate that is heated by the hot gas discharge line. The hot gas discharge line is routed beneath the metal plate before traveling to the condenser. The heat plate causes defrost water to completely evaporate before another defrost cycle begins. This process serves a dual purposes, since it both disposes of water and removes superheat from the hot gas as it travels beneath the plate.

The condensate drain line can become plugged with debris or with algae that grows in damp cold climates. A plugged drain line causes the condensate pan to overflow, with the result that water accumulates and freezes. This drain should be cleaned about once per year by pouring two cups of hot (not boiling) water through it.

Troubleshooting. A severely frosted evaporator, called a ***freeze-up,*** indicates trouble with an electric defrost system. A freeze-up will result in a sharp rise in cabinet temperature. This condition might be described by a customer in these terms: "the food in the freezer section is thawing, the milk is warm, and the unit runs constantly."

This problem can be caused by one of four items:

- a defective evaporator fan.
- a defective timeclock.
- a burned-out electric defrost heater.
- a defective defrost termination thermostat.

A defective evaporator fan is not unusual; a defective timeclock is rather common. The defrost heater will occasionally burn out, but the defrost terminator rarely fails.

Troubleshooting procedure. Remove the cover panel to gain access to the evaporator. The evaporator fan should operate whenever the compressor is running. If the fan is okay, use a screwdriver to switch the timeclock into defrost. The compressor and evaporator fan should both stop and the defrost heater will be energized. Place a clamp-on ammeter around the wire supplying power to the defrost heater to check for a reading of 6A to 10A.

If the heater is okay, permit the system to defrost. The problem is a defective timeclock (it cannot switch from run to defrost).

The timeclock can be checked with an ohmmeter. First, disconnect power and remove the timeclock from the unit. Resistance through the motor should be about 2400Ω. Check continuity through the switches while rotating the cam with a screwdriver. See Fig. 24-9.

There should *never* be continuity between terminals 2 and 4. If this occurs, the defrost heater is being energized during the run cycle; more heat is being added than the system can remove. The defrost heater will cycle on the termination thermostat, allowing temperatures to return to normal until the terminator thermostat closes again. These symptoms may be incorrectly diagnosed as a moisture restriction in the capillary tube or a defective compressor.

Visual inspection of the defrost heater will usually permit you to detect a burnout or wiring problem. An ohmmeter can be used to check proper resistance through each heater. The appliance schematic normally shows the resistance value for each heater.

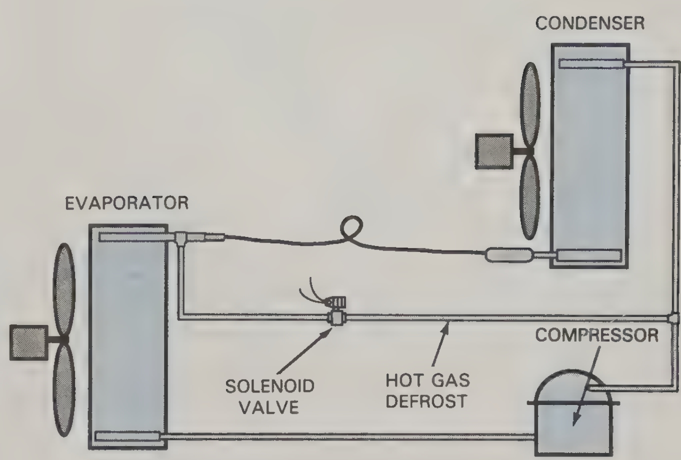


Fig. 24-10. A domestic hot gas defrost system directs hot gas from the compressor directly to the evaporator, where it quickly melts accumulated ice. The hot gas defrost line should be connected as close to the compressor as possible.

Domestic hot gas defrost cycle

The ***hot gas defrost*** cycle is very different from electric defrost. Gas is taken directly from the hot gas discharge line (close to the compressor) and delivered directly to the evaporator inlet. See Fig. 24-10. This 1/4 in. copper tube is factory installed to bypass the condenser and refrigerant control. To control flow, a solenoid valve is located in this hot gas bypass line, within the condensing unit area. When the solenoid valve is energized and opens, hot gas will take the path of least resistance and travel directly to the evaporator inlet. When the solenoid valve closes, the hot gas must travel through the condenser.

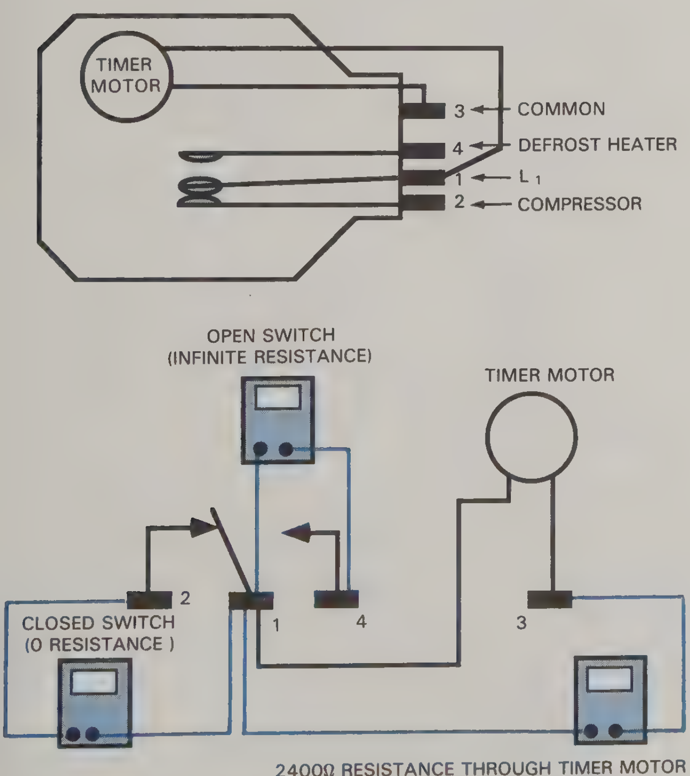


Fig. 24-9. An ohmmeter is used to check the defrost timeclock to determine whether it is operating properly or whether it is defective. Before testing is attempted, all wiring must be disconnected from the timeclock.

During defrost, the timeclock energizes the solenoid valve and stops the evaporator fan. The compressor continues to operate during defrost to produce the necessary hot gas. The hot gas will quickly melt any frost accumulation as it travels through the evaporator and into the suction line.

Any system using hot gas defrost *must* include protection against liquid floodback to the compressor, since it is possible for hot gas to condense in the cold evaporator and enter the suction line as liquid. Protection against liquid floodback is usually provided by a suction accumulator. On domestic systems, the suction accumulator is a special chamber located on the evaporator outlet.

Wiring connections. For domestic hot gas defrost systems, the timer must control the solenoid and the evaporator fan. The clock must have a set of normally open contacts (for the solenoid) and a set of normally closed contacts (for the evaporator fan). The thermostat is connected in series with power supply to the timer, and the power supply to the compressor. The timer must *not* control the compressor. See Fig. 24-11.

The timer operates on accumulated running time, and cannot place the system into defrost unless the thermostat contacts are closed. This procedure assures that the compressor is operating and producing hot gas when the clock calls for defrost. Frequency and duration of defrost is controlled by the timer (time-initiated/time-terminated). The required number and length of defrost cycles is determined by the appliance manufacturer, so the clock is nonadjustable. A defrost termination thermostat is not needed.

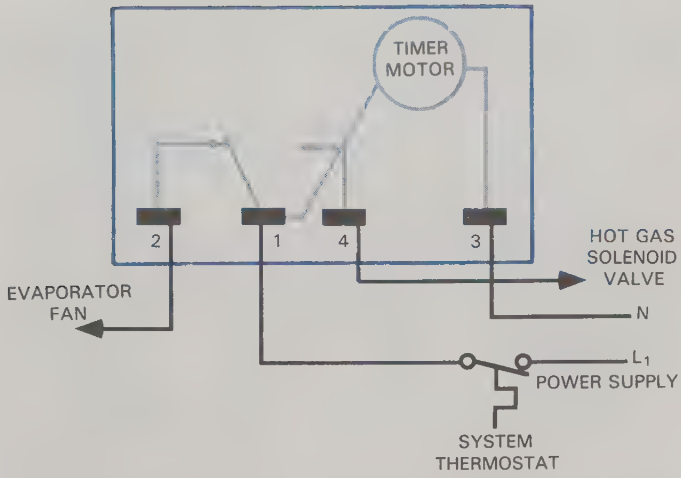


Fig. 24-11. The thermostat is wired in series with both the timer and the compressor. The timer must not control the compressor, since it provides the hot gas for defrosting the evaporator.

Troubleshooting. During defrost, head pressure (when using R-12) will drop to about 70 psig (483 kPa) because the condenser and capillary tube are bypassed. Suction pressure rises according to evaporator temperature. Compressor amperage is reduced because the compressor is operating under an almost "no load" condition. Defrost must occur rather quickly (5 to 10 minutes) because a prolonged defrost produces very little hot gas.

Problems with hot gas defrost systems usually can be traced to a defective timer, or to the system being low on refrigerant. Low head pressure (as a result of low ambient temperature) will not produce sufficient hot gas for defrost. The evaporator will eventually freeze up. This problem seldom occurs with *domestic* systems, since the appliance is located inside where the ambient is typically about 70°F (21°C).

Domestic accessories

Domestic refrigerator-freezers have become quite advanced, with manufacturers adding such items as icemakers and dispensers for milk, juice, or water. These devices are not controlled by the timer. It is necessary to consult the appliance schematic when servicing these units.

Standard accessories for most refrigerator-freezers involve door switches that turn interior lights on and off. Sometimes, the door switch for the freezer section will control both the light and the evaporator fan. When the freezer door is opened, the light is turned on and the evaporator fan is turned off. Stopping the fan keeps warm moist air from being drawn into the freezer. The lighting circuits are connected parallel and do not affect other system components.

Refrigerator-freezers also contain resistance heaters inside the door frames. These heaters prevent condensation of moisture around the doors during periods of high humidity. Door frame heaters are often called *mullion heaters* or "anti-sweat heaters". Sometimes a manual energy saving switch is provided to allow turning off door heaters during the winter (low humidity) months.

A small heater is often used inside the butter storage compartment. This heater is called a "butter conditioner" and maintains proper temperature to prevent butter from getting too hard. These and other small resistance heaters are designed to operate continuously. Fig. 24-12 shows a complete pictorial diagram of a modern refrigerator-freezer. The same appliance is shown in schematic form in Fig. 24-13.

COMMERCIAL OFF-CYCLE DEFROST

Off-cycle defrost is often used on such light commercial systems as small walk-in coolers and self-contained cases. These systems normally operate with R-12 and maintain an air temperature between 38°F and 32°F (3°C and 0°C). A low-pressure control or an air-sensitive thermostat controls the air temperature. The low-pressure control is set to cut in at 35 psig (38°F) and cut out at 14 psig (12°F, less 2 psig for pressure drop).

During the run cycle, evaporator temperature is below 32°F, so frost will accumulate. When air temperature is reduced to 32°F (0°C), the evaporator is 22°F (-6°C) and refrigerant is 12°F (-11°C).

After cut-out, the air temperature, evaporator temperature, and refrigerant temperature will quickly equalize at 32°F. The evaporator fan runs continuously. As air temperature increases, heat is absorbed by melting frost off the evaporator. The latent heat of melting ice (144 Btu/lb.) helps maintain cabinet temperature during the off cycle. The temperature must be warmed to 38°F (35 psig) before the low pressure control (or thermostat) will reach the cut-in point. All frost will melt before the evaporator warms up to 38° F.

There are occasions when an off-cycle defrost that uses an air- sensitive thermostat will have an excessively long run cycle. Frost accumulation becomes extremely heavy and stops airflow over the evaporator. The evaporator becomes colder and accumulates more frost. Air temperature rises sharply due to lack of heat transfer.

This heavy frost usually occurs during normal working hours, when the door of the cooler or case is opened frequently. After normal working hours, evaporator frost is thick, so very little heat transfer is taking place. The system is unable to satisfy the air-sensitive thermostat. In such circumstances, defrost is accomplished by manually turning off the condensing unit for about two hours. The evaporator fan will continue to operate and thus melt the frost accumulation.

COMMERCIAL OFF-TIME DEFROST

Automatic off-time defrost is accomplished by installing an inexpensive timer that turns the condensing unit off for two hours each evening. Typically, the timer is set to accomplish defrost between midnight and 2 a.m.

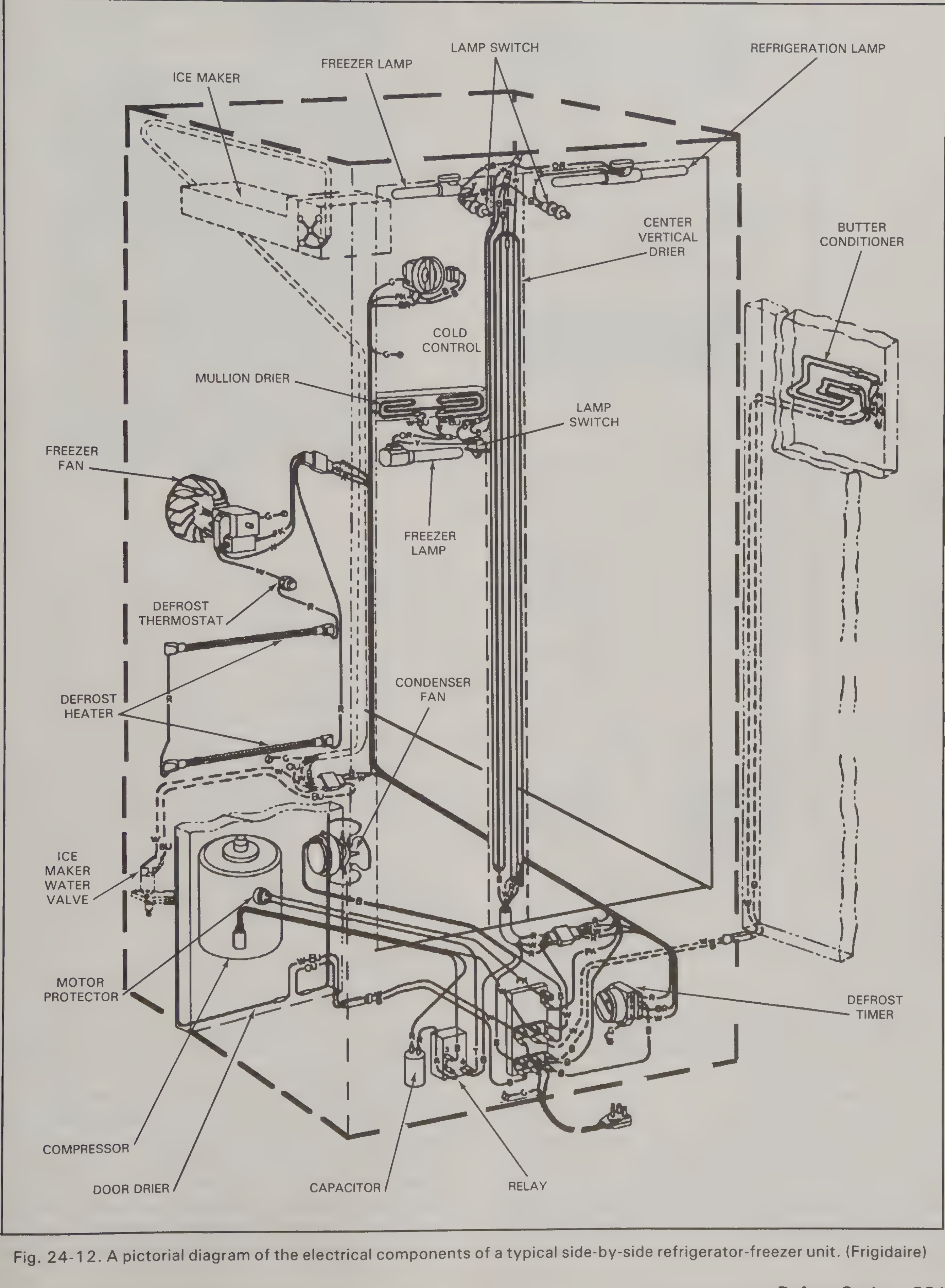


Fig. 24-12. A pictorial diagram of the electrical components of a typical side-by-side refrigerator-freezer unit. (Frigidaire)

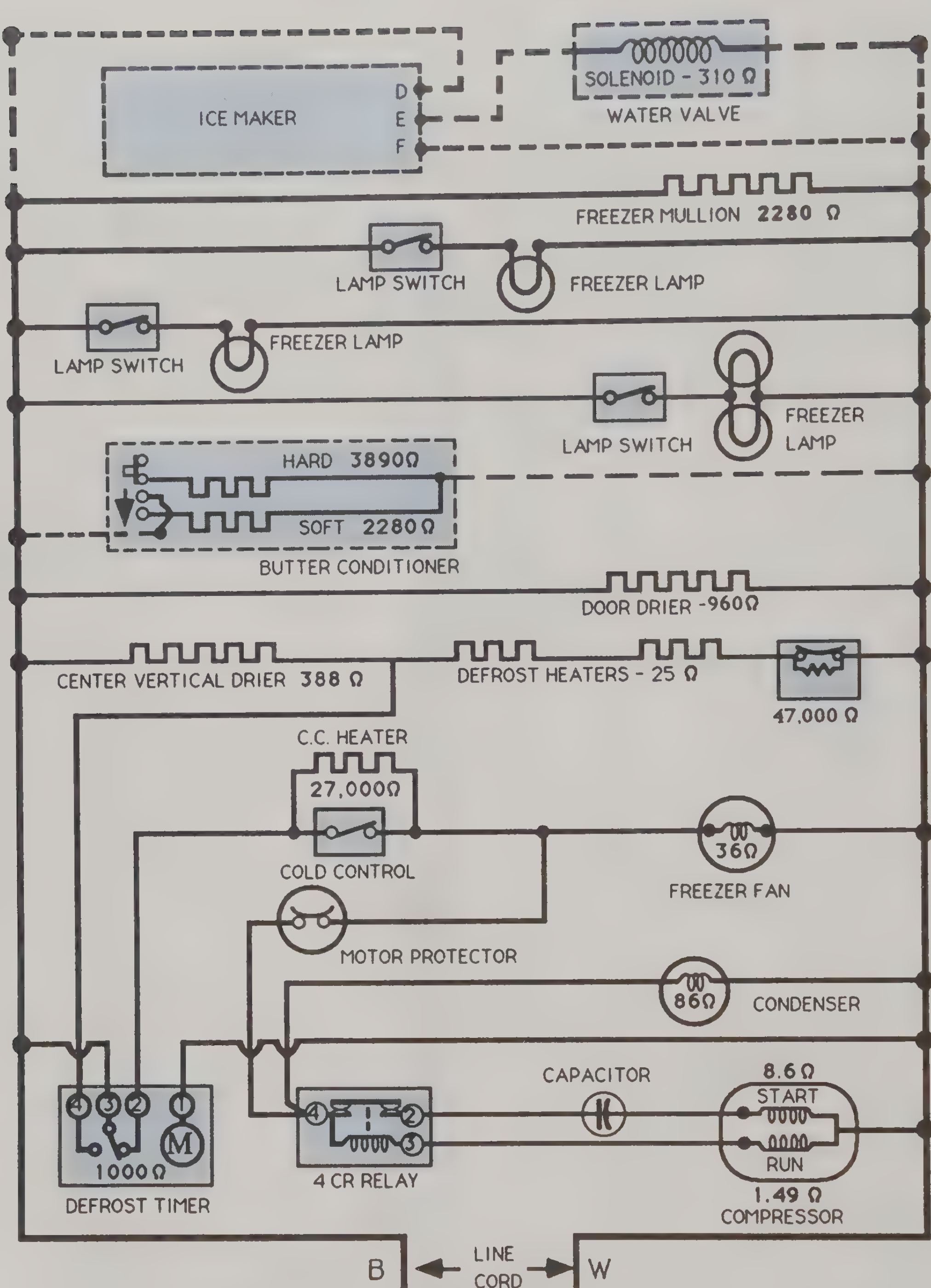


Fig. 24-13. A schematic diagram of the electrical components of a typical side-by-side refrigerator-freezer unit. (Frigidaire)

After defrost, the system reduces air temperature in the cooler to the desired level before normal working hours.

Off-time defrost timer

A typical timeclock used for off-time defrost is shown in Fig. 24-14. Commercial refrigeration defrost timeclocks operate on a 24-hour basis, with the large dial face divided into two 12 hour sections. The twelve nighttime hours (6 p.m. to 6 a.m.) are dark-shaded for easy identification. The stationary pointer should indicate correct time of day on the dial face. The dial face slowly rotates clockwise past the pointer to show the correct time of day. The dial face can be rotated manually to reset the time.

Two metal pointers (one light and one dark) are furnished for attaching with screws to the outer edge of the dial face. The light colored pointer is anchored at the time when the defrost should begin.

The dark pointer is anchored at the time when defrost should end. Minimum defrost period is two hours. As the dial turns and the light-colored pointer reaches the fixed pointer, a lever is tripped and a sharp "click"

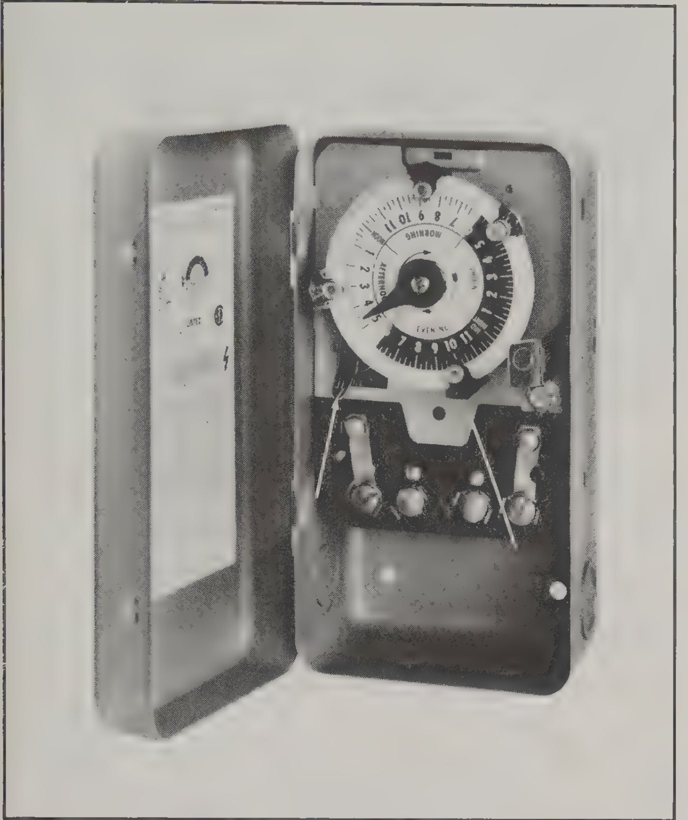


Fig. 24-14. A commercial automatic off-time defrost timer. Metal pointers are attached to the dial face to start and stop the defrost cycle. This timer is set up for two defrost cycles in a 24-hour period: one beginning at 3 p.m. and ending at 10 p.m., and the second beginning at 5 a.m. and ending at 8:45 a.m. The manual lever can be used to start and stop a defrost cycle manually. (Paragon Electric Co.)

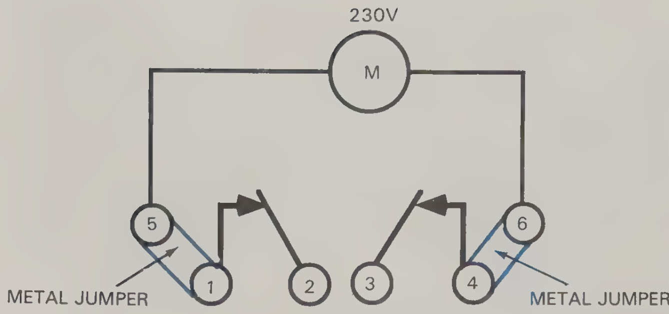


Fig. 24-15. Electrical schematic for the commercial automatic timeclock shown in Fig. 24-14. The metal jumpers are factory installed to provide power to the timer motor from the power supply connected to terminals 1 and 4.

is heard when the clock's two switches open. This starts the defrost cycle. The dial continues to turn until the dark-colored pointer reaches the fixed pointer. Another sharp "click" will be heard as the two switches close. This ends the defrost cycle.

A small lever located at the lower left of the dial face permits manual operation of the switches. The technician must remember to manually terminate the defrost cycle by returning this lever to its proper position when finished.

Electrical connections

Most commercial timer switches are rated to carry 40 amps per switch. The timeclock is available in either 120V or 208V-240V configurations to provide easy matching of voltages. The gray steel case is equipped with standard knockouts for attaching electrical box connectors. An electrical schematic drawing, like the one shown in Fig. 24-15, is located inside the case cover to explain connections for the clock motor and switches.

As shown in Fig. 24-15, one normally closed switch is located between terminals 1 and 2, and the other normally closed switch is located between terminals 3 and 4. The two power supply wires are connected to terminals 1 and 4. This connection provides power to each switch and the factory installed jumper bars transfer power supply to each side of the clock motor at terminals 5 and 6.

On 208V-240V systems, both switches are used to disconnect power supply to the condensing unit. On 120V systems, the jumper bar between Terminals 4 and 6 is omitted by the factory, since it is unsafe to install switches in the neutral (white) wire. The second switch is not needed on a 120V system, so the neutral wire is connected to terminal 6.

On commercial systems, power supply to the timeclock motor must never be disconnected. The thermostat or low-pressure control is connected in series with one side of the line between the timeclock and condensing unit. See Fig. 24-16.

Troubleshooting

The timer motor can be checked for proper rotation by noting the position of the pointer and waiting one-half

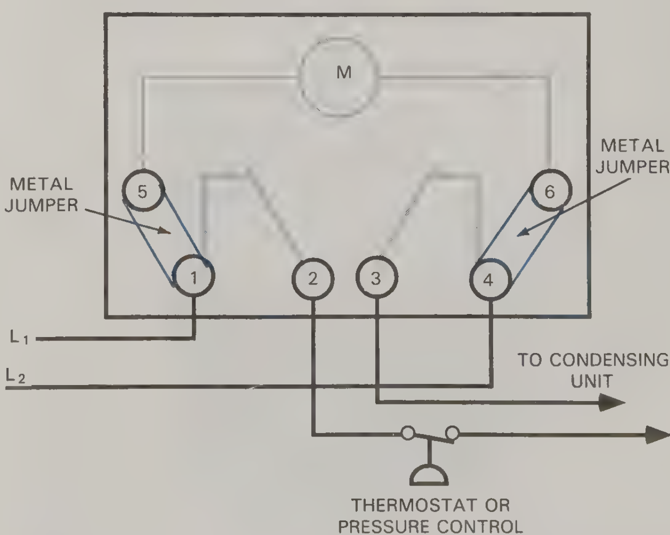


Fig. 24-16. The thermostat or low-pressure control is connected in series with one side of the line supplying power to the condensing unit. The timer controls both switches, opening or closing them at the same time.

hour to see if the dial turned the proper distance on the scale. An ohmmeter can be used to check resistance of the timer motor (it should be between 1800Ω and 2000Ω). After disconnecting the power supply, remove the clock body from the metal case to visually inspect the clock parts and switches. The dial face can be rotated by hand so you can observe opening and closing of the switches.

COMMERCIAL ELECTRIC DEFROST

Electric defrost is popular for commercial refrigeration systems because the defrost period is short and easily controlled. A timeclock is used to ***initiate*** the defrost cycle according to time of day, Fig. 24-17. Termination can be accomplished by time, by evaporator temperature, or by suction pressure. Each has advantages and limitations. Commercial defrost timeclocks can be separated into three general types, depending upon the method of termination:

- Time-initiated/time-terminated.
- Time-initiated/temperature-terminated.
- Time-initiated/pressure-terminated.

Time-initiated/time-terminated

The ***time-initiated/time-terminated clock*** is used to place the system into defrost according to time of day, and ***terminate*** the defrost cycle after a specified length of time. The clock contains a normally closed (NC) switch and a normally open (NO) switch for controlling the compressor, evaporator fan, and defrost heaters. As shown in Fig. 24-18, the large dial face is divided into two 12-hour sections, with nighttime hours (6 p.m. to 6 a.m.) dark-shaded. The dial face turns counterclockwise (CCW) and has a stationary pointer to indicate the

Fig. 24-17. Commercial electric defrost systems use timeclocks like this one to initiate the defrost cycle. Termination can be by time, temperature, or pressure. (Paragon Electric Co.)

Fig. 24-18. A timer used for time-initiated/time-terminated defrost. The timer setting will provide one defrost cycle beginning at midnight (note pin on outer dial) and lasting 60 minutes (as indicated by pointer at 60 on notched inner dial). Several different cycles could be programmed at different times, but all would have to be the same length. (Paragon Electric Co.)

proper time of day. Holes are drilled and threaded around the outer edge of the dial face at all even-numbered hours. Metal pins are provided to screw into these threaded holes to determine what time of day the system will enter a defrost cycle. The number of pins determine how many defrost cycles occur each day.

The large clock dial completes one rotation every 24 hours. When a pin nears the stationary pointer, it trips a lever and places the system in a defrost cycle. (The tripped lever opens the NC contact and closes the NO contact.) As noted, the pins are used to place the system *into* the defrost cycle.

The knob and small dial located in the center of the large dial is used to determine the duration (length of time) of the defrost cycle. The small dial is calibrated in minutes, and is sometimes referred to as the "fail-safe" dial. The outer edge of the dial contains notches which are calibrated at two-minute intervals (up to 110 minutes). To set the length of the defrost cycle, the pointer is depressed and moved to indicate desired number of minutes (the termination point). The pointer will trip the switches back to their original positions when the specified number of minutes has passed.

The knob attached to the smaller dial is used to manually advance both dials together. This knob is turned counterclockwise (CCW) for setting the correct time of day, placing the system into defrost, or taking the system out of a defrost cycle.

Defrost requirements. The time-initiated/time-terminated defrost cycle cannot adjust itself to seasonal changes. Adjustments are required to compensate for summer (high humidity) versus winter (low humidity). Longer defrost periods are required during summer months, when there is heavier frost accumulation. Less frost occurs during fall and winter, when the humidity is lower.

Length of defrost must be sufficient to completely remove the frost from the evaporator during any season. Partial defrosts will result in slow but steady accumulation of ice and result in a freeze-up. Longer, but less frequent, defrosts are preferred over frequent short defrosts.

Electrical connections. The timer just described is available in 120V or 208V-240V configuration, with contacts rated at 40A. Power supply must be connected to terminals N and X for continuous power supply to the clock motor. See Fig. 24-19. A jumper bar installed at the factory transfers the power supply from terminal N to one side of the switches at terminals 1 and 2. The switch between terminals 1 and 3 is normally open and the switch between terminals 2 and 4 is normally closed.

Power supply to the defrost heaters is obtained at terminal 3 (NO); the other side of the heaters is connected at terminal X (Common). The compressor and evaporator fan are connected to terminals 4 (NC) and X. Each switch is controlled by one side of the power supply. Terminal X is called "common" because all components use that terminal to obtain the other side of power supply. See Fig. 24-20.

In commercial systems, power supply to the timeclock is never interrupted. The primary motor control (thermostat or pressure control) must be connected in series between the clock (NC) contacts and the compressor. On three-phase electrical systems, terminal 4 (NC contact) is used to control power supply to the contactor coil.

Troubleshooting. Trouble with the timeclock is usually due to improper defrost time settings. Failure may consist of a burned-out timer motor or burned-out contacts on the switches. Resistance of the timer motor is about 2800Ω. Proper operation of the motor and gears can be checked by using a pencil to mark the position of the dials, waiting about one-half hour, then rechecking the dials for proper rotation.

The entire timer body can be removed from the case for visual inspection. After disconnecting power supply, remove clock from case. Manually rotate the dials by turning the knob counterclockwise and observing the switches for proper operation. Visual inspection usually reveals any malfunction.

Field repairs to the timeclock and switches are not recommended; they should be replaced. A new clock is far less costly than the loss of product and sales due to continued defrost problems.

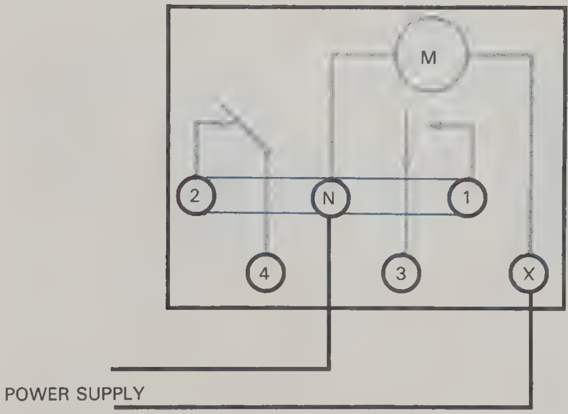


Fig. 24-19. Power supply to the timer is connected to terminals N and X. A factory installed jumper bar connects terminals N, 1, and 2.

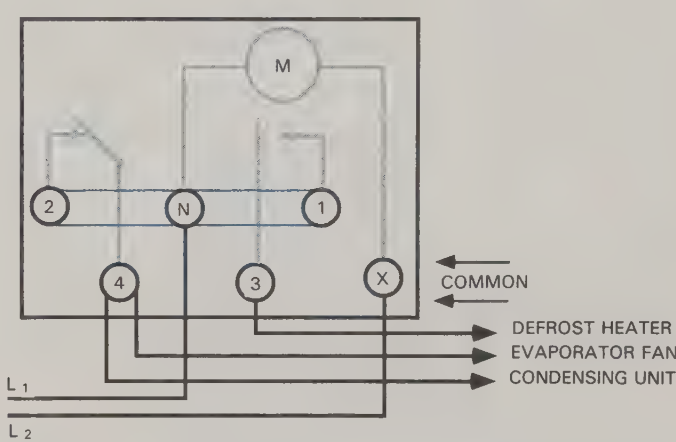


Fig. 24-20. Terminal X is the "common" terminal for the timer, since it serves as one side of the power supply for all the timer-controlled components of the system.

Evaporator fan delay thermostat

On low-temperature systems (freezers), the evaporator fan must not be permitted to restart immediately after defrost. The evaporator becomes very warm (about 55°F to 60°F or 13°C to 16°C) during defrost, and when defrost ends, the fan would blow evaporator heat into the storage area. This heat would cause moisture to condense on the ceiling panels, then drip down onto the product and freeze. A special ***evaporator fan delay thermostat*** is used to delay restarting of the fan until evaporator temperature drops to about 5°F (-15°C).

The fan delay thermostat has a bimetallic disc with normally closed contacts that open on rising temperature (at about 20°F or -7°C) and close on falling temperature (at about 5°F or -15°C). See Fig. 24-21. The fan control setting (such as F-20 or F-38) is usually stamped on the control body. This thermostat is connected in series with one side of the power supply to the evaporator fan. The thermostat is mounted or clamped directly to the evaporator (on the return bends).

The contacts will open when the evaporator temperature reaches about 20°F (-7°C) . When the defrost

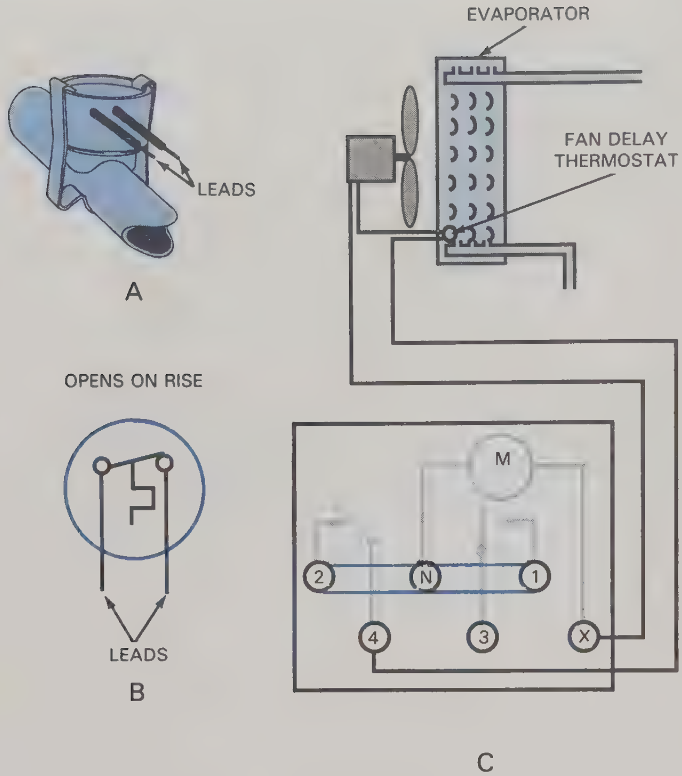


Fig. 24-21. The evaporator fan time-delay thermostat is a means of restricting fan operation until temperatures have dropped sufficiently to avoid condensation problems. A–Mounting of the thermostat on evaporator tubing. B–Schematic symbol. C–Wiring connections to timeclock.

cycle is terminated, this thermostat will keep the fan from operating until the evaporator temperature is lowered to about 5°F (-15°C).

Troubleshooting. Failure of the fan delay thermostat is rather rare. When this control *does* fail, however, it is usually in the open position due to burned-out contacts. This prevents the evaporator fan from operating and a freeze-up will occur. To test, be certain the control is cold enough for the thermostat contacts to close, and then jumper the control to "make" (close) the switch. If the fan operates, the control is defective and should be replaced. If the fan does not operate after jumpering the control, the switch is already closed.

If the fan delay thermostat fails in the closed position, the fan will be controlled by the timeclock and will operate immediately after defrost (no delay). This problem is identified by excessive heat and moisture following a defrost cycle. It can be tested by heating the fan control sensor to the cut-out point with warm water.

Time-initiated/temperature-terminated

Time-terminated defrosts are difficult to program due to such factors as seasonal changes, number of door openings, restocking of product, humidity, and temperature. Length of defrost must allow for *maximum* frost accumulation. Many times, the defrost cycle could be much shorter than programmed, due to less frost. Excessive defrost time causes moisture problems, adds heat load, and wastes energy. To overcome this problem, a temperature termination feature was added to time-terminated systems to stop the defrost when evaporator temperature reaches a level that indicates all frost has been removed.

Temperature-terminated timeclock. A ***temperature-terminated timeclock*** initiates defrost according to time of day, but termination is controlled by a thermostat mounted on the evaporator. The termination thermostat senses evaporator temperature. This defrost system has the advantage of automatically adjusting to seasonal changes and maintaining a minimum defrost time. This eliminates guesswork in setting defrost length and making seasonal adjustments.

This timeclock includes a small solenoid with a plunger that is mechanically connected to the clock's trip lever. See Fig. 24-22. Internal wiring connections prevent the solenoid from being energized except during a defrost cycle. When the solenoid is energized by the termination thermostat, the plunger trips the lever and ends the defrost cycle, regardless of time remaining on the small dial. The timeclock initiates the defrost cycle, but the thermostat and solenoid end it when evaporator temperature indicates the frost has been melted.

Uninterrupted power supply to the clock is connected to terminals 1 and N because the timer motor is internally connected to these terminals. The factory installed jumper bar transfers power supply from terminal 1 to the normally closed contacts at terminal 2. The normally open contact is located between terminals 1 and 3, and the normally closed contact is located between terminals 2 and 4.

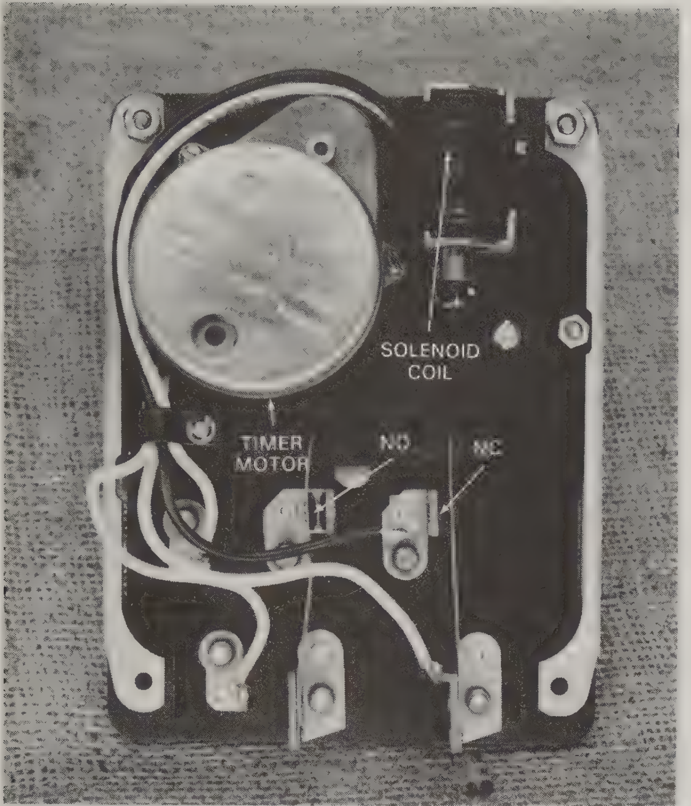
One side of power supply to the small solenoid is factory connected to terminal 3 (NO switch). This prevents the solenoid from being energized except during a defrost cycle, when the switch is closed. The other side of the solenoid is factory connected to terminal X. The termination thermostat is connected between X and N, thus completing the solenoid circuit to common.

Fail-safe feature. When temperature (or pressure) is used to terminate defrost, the small dial on the timeclock is used for safety (which is why it is often referred to as a "fail-safe"). The ***fail-safe setting*** must allow sufficient time to perform a complete defrost of maximum frost accumulation. If temperature or pressure termination components fail to operate properly, this backup feature permits the fail-safe to terminate the defrost cycle.

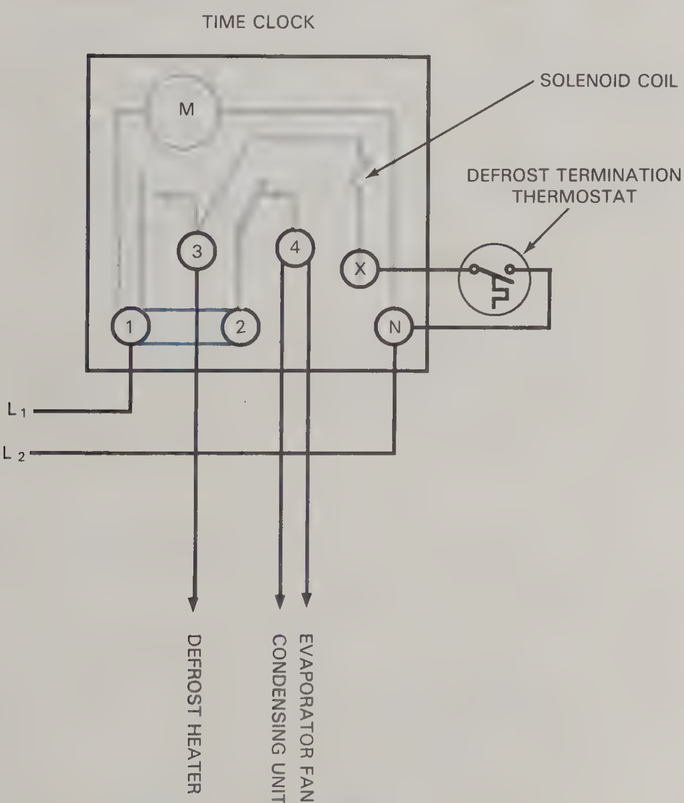
Defrost termination thermostat. The defrost termination thermostat contacts *close on rising temperature.* The contacts close when evaporator temperature reaches the thermostat's setpoint. The setpoints (cut-in and cut-out) will vary according to the application and the manufacturer's specification. On a "high limit" type

thermostat, the cut-in (L-50, L-55) is normally stamped on the control body. This type of thermostat is nonadjustable and frequently found on evaporators located inside walk-in freezers, coolers, and display cases.

The *adjustable-type* defrost termination thermostat is commonly used for commercial display cases. See Fig. 24-23. This thermostat is normally located behind the kick rail (toe plate) of the case for ease in making wiring connections and adjustments. The sensing element is attached to the evaporator, usually located in



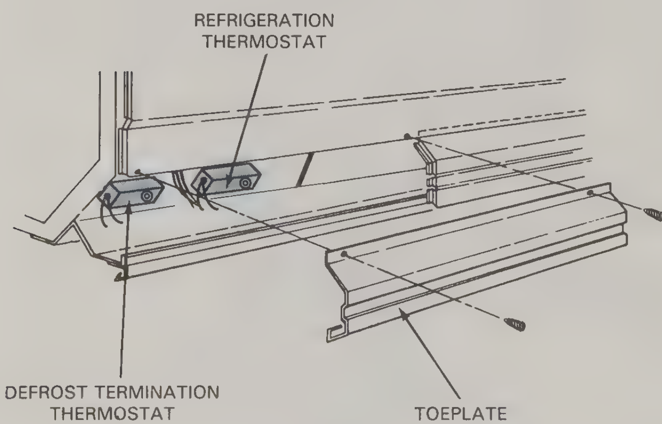
A



B

Fig. 24-22. Time-initiated/temperature-terminated timeclock. A–Rear view of timeclock, showing the solenoid that operates the trip lever. (Paragon Electric Co.) B–Schematic showing electrical connections. The thermostat closes on rising temperature.

A



B

Fig. 24-23. Adjustable defrost termination thermostat. A–Thermostat and sensing element. (White-Rodgers) B–The thermostat is usually mounted behind the toeplate of the refrigerated display case.

the bottom of the case. A capillary tube linkage transfers bulb temperature to the control body.

Troubleshooting. Termination problems can occur if the clock solenoid burns out, or if the termination thermostat fails or is not properly adjusted. This problem becomes evident when the customer complains, "the system gets too hot during defrost and the product tends to thaw out, but refreezes during the run cycle." Such complaints are often heard during the first heat wave of the summer.

The technician must first determine which type of defrost clock is involved. A time-initiated/time-terminated clock may need manual readjustment. A time-initiated/temperature-terminated clock may be having either solenoid or thermostat problems. The solenoid may be burned out and cannot physically trip the lever to terminate defrost. Visual inspection of the solenoid usually will reveal if there is a burnout, but an ohmmeter reading of *infinite resistance* will confirm it. If the solenoid is burned out and a replacement clock is not readily available, the fail-safe can be adjusted to operate the defrost in a time-terminated mode until a replacement is obtained.

If the clock solenoid is functioning properly, the termination thermostat can be checked. Do so by manually placing the clock into a defrost cycle. Jumper the thermostat connections across clock terminals X and N. If the clock switches out of the defrost cycle, the thermostat is defective or improperly adjusted. If the clock *remains* in defrost, the clock itself is defective.

Combination fan delay and defrost termination

Sometimes the fan delay thermostat and defrost termination thermostat are combined into one component. This device is often used for walk-in coolers and freezers where the evaporator and fan are readily accessible. The combination thermostat is easily recognized because it has three wires rather than two, Fig. 24-24.

The three wires are marked C (for common), F (for fan), and T (for terminator). Power supply to the control is obtained from the timeclock at terminal N and is connected to terminal C on the control. This connection supplies power from the clock to the movable pole inside the control, Fig. 24-25. The connection is called *common* because it supplies power to both control switches.

Fig. 24-26 illustrates a typical commercial defrost system using fan delay and defrost termination. One side of the power supply to the evaporator fan is connected to terminal F on the thermostat and the other side to the normally closed switch on the timeclock. This connection places a switch in each wire supplying power to the evaporator fan. A wire from terminal T of the thermostat is connected to the timeclock at Terminal X and serves as the defrost termination connection. This connection also places a switch in each wire supplying power to the small solenoid inside the timeclock.

During a normal run cycle, the evaporator fan will operate because the timeclock switch is closed and the fan delay switch is closed (since the evaporator is cold). Both switches controlling power supply to the solenoid inside the timeclock are open.

At time of defrost, the clock stops the evaporator fan and condensing unit (the NC switch in the timeclock will open). The timeclock's NO switch closes and energizes the defrost heater. Closing of this switch also connects one side of the power supply to the clock solenoid.

As evaporator temperature rises quickly, the movable pole in the combination thermostat will warp to the mid-position where both control switches are open. The control remains in the mid-position until the evaporator temperature reaches 50°F to 55°F (10°C to 13°C). This temperature further warps the movable pole, closing the contact to the T position. This completes the circuit to the clock solenoid, terminating the defrost cycle.

The evaporator fan cannot restart until evaporator temperature becomes cold enough to cause the movable pole of the thermostat to warp back to the F contact. This movement also opens the contact at T, disconnecting the solenoid.

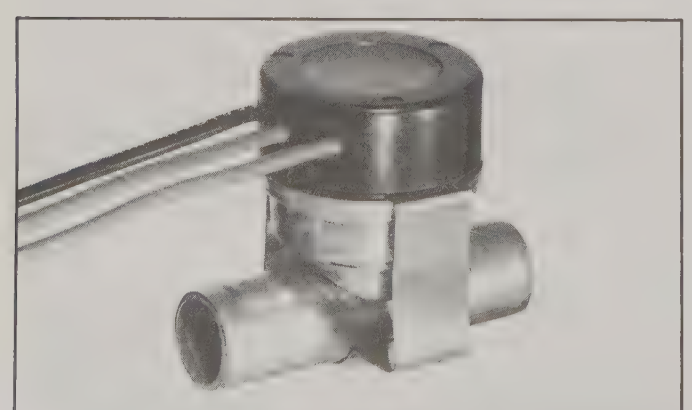


Fig. 24-24. This combination fan delay and defrost termination thermostat clamps to the evaporator tubing.

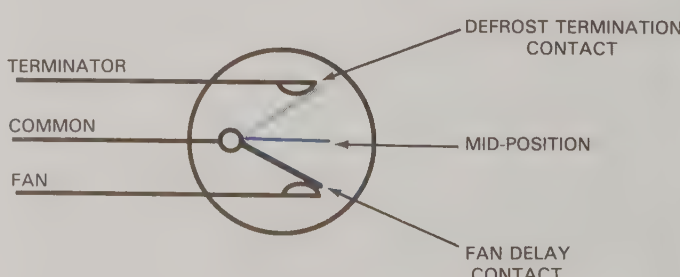


Fig. 24-25. A movable pole inside the combination fan delay and defrost termination thermostat permits it to perform both functions. During normal operation, the contact is in the fan position. In the defrost cycle, the pole will move to the mid-position as the temperature of the evaporator begins to rise. When evaporator temperature indicates all frost has melted, the pole moves to the defrost termination contact.

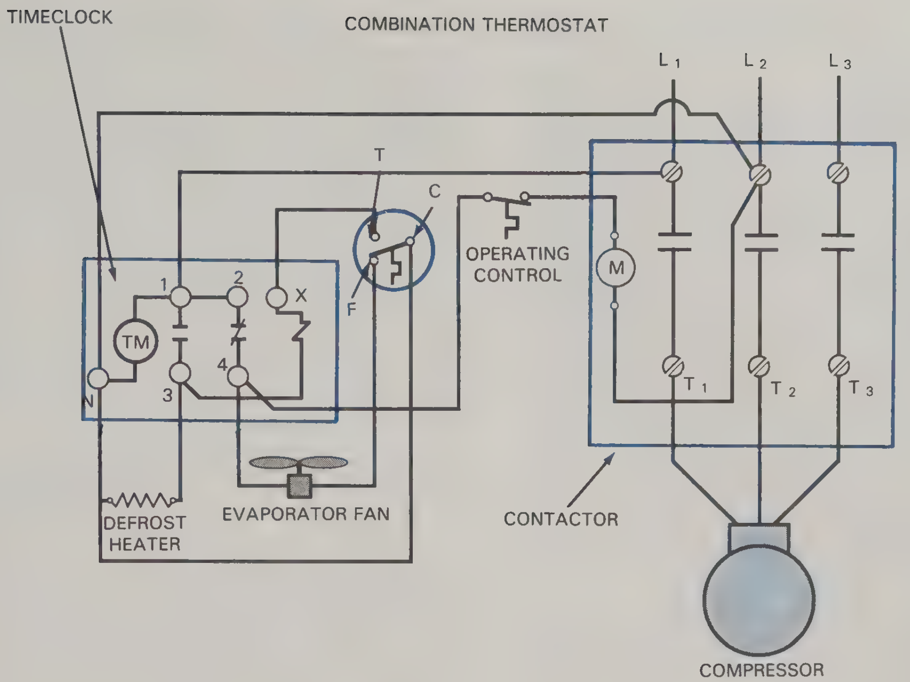


Fig. 24-26. Schematic for system using combination fan delay and defrost termination thermostat.

Troubleshooting. Troubleshooting the combination thermostat is accomplished by checking each switch for proper operation. When checking the evaporator fan or fans, remember that there may be different reasons for non-operation: the fan delay thermostat may be functioning, or the fan may be defective (burned out). Another possibility is a defective door switch. Many walk-in freezers have a door switch that turns off the evaporator fans when the door is opened. This prevents warm moisture-laden air from being drawn into the freezer when the door is open. Stopping the fans will cause the evaporator temperature-pressure to drop rather quickly and the condensing unit will shut off on a low-pressure control. When the door is closed and fans operating, pressure quickly rises and the condensing unit is turned back on by the same low-pressure control.

Evaporators that have multiple fans are easier to check than single-fan evaporators. Multiple evaporator fans are always connected in parallel because airflow across the evaporator is critical. One fan motor may burn out, but others continue to operate. If one fan stops functioning, a partial freeze-up will occur at that location. Power and control to evaporator fans is proven when at least one fan is operating.

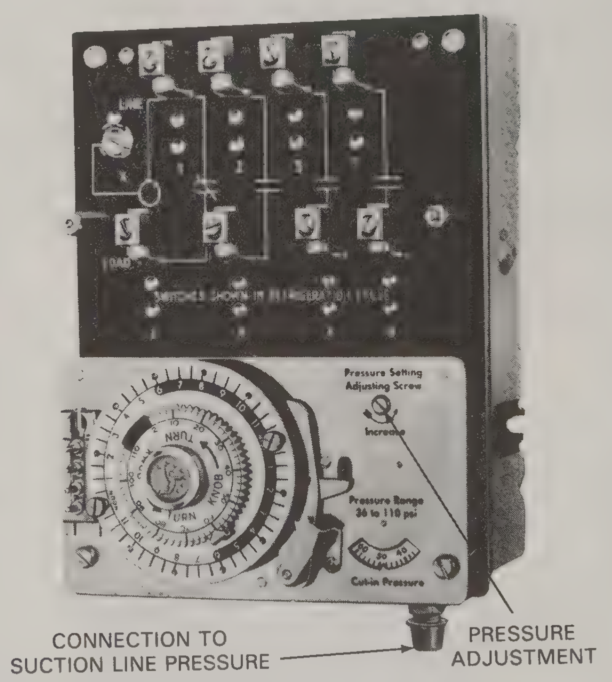


Fig. 24-27. A time-initiated/pressure-terminated timeclock. (Paragon Electric Co.)

Time-initiated/pressure-terminated

The *time-initiated/pressure-terminated timeclock* is similar to the timeclocks discussed previously, except that termination is accomplished by rising pressure in the suction line. See Fig. 24-27. The clock is located at the compressor, with a 1/4 in. copper tube linking the clock diaphragm to suction pressure at the compressor. During defrost, suction pressure rises. This pressure rise moves a diaphragm that is linked mechanically to the timer lever. The appropriate rise in suction pressure will cause the defrost cycle to terminate.

The clock is used to turn the compressor off, energize electric defrost heaters, and stop evaporator fan(s).

During defrost, suction pressure will reflect evaporator temperature according to the temperature-pressure chart. When suction pressure rises to the clock's setpoint, the diaphragm trips the clock lever and terminates the defrost cycle.

The pressure required to trip the clock lever is adjustable. An adjustment screw (and scale) are provided on the clock, as shown in Fig. 24-27. The scale is calibrated from 36 psig to 110 psig (248 kPa to 758 kPa), so the same clock can be used for R-12, R-22, or R-502. Termination pressure settings for R-12 can be from 38 psig to 45 psig (262 kPa to 310 kPa). This results in an evaporator temperature of 35°F to 40°F (2°C to 4°C). The pressure setting for R-22 is 85 psig (586 kPa), which results in an evaporator temperature of about 50°F. Termination pressure setting for R-502 is 95 psig (655 kPa). This results in an evaporator temperature of 49°F (9°C).

Frequency of defrost will vary according to the system, but the fail-safe should be set for 45 to 60 minutes. This recommendation is approximate, but the setting should result in defrost being terminated by *pressure,* rather than time.

Pressure-terminated clocks cannot be used on pumpdown cycles because refrigerant does not remain in the low-pressure side during the off (defrost) cycle.

Troubleshooting. Power supply to the clock should always be checked first. Checking for proper rotation of timer dials is standard procedure. Mark location of the dials and check rotation against elapsed time. The clock can be removed from the case for visual inspection, if desired.

To check accuracy of the calibrated dial (termination pressure), install a gauge manifold on the compressor service valves. Turn clock dials to place system into the defrost cycle. Slowly bleed some high-pressure gas through the gauge manifold and into the low-pressure side to raise the suction pressure to the termination point. Close manifold valves and observe the suction pressure while listening for a definite "click" as the timeclock terminates. Always double-check the setting to be certain that the clock is consistent and not erratic in its operation.

COMMERCIAL HOT GAS DEFROST

Commercial hot gas defrost systems are rather common, with operation similar to the domestic systems described earlier in this chapter. Hot gas is taken directly from the hot gas discharge line (close to the compressor) and delivered directly to the evaporator inlet. See Fig. 24-28. A solenoid valve is located in the hot gas bypass line to control flow. When the solenoid valve is open, hot gas travels directly to the evaporator inlet, bypassing the condenser, receiver, and refrigerant control. When the solenoid valve is closed, however, hot gas *must* follow its normal route through the condenser.

The defrost timer is used to control electrical circuits to the hot gas solenoid valve and evaporator fan (or

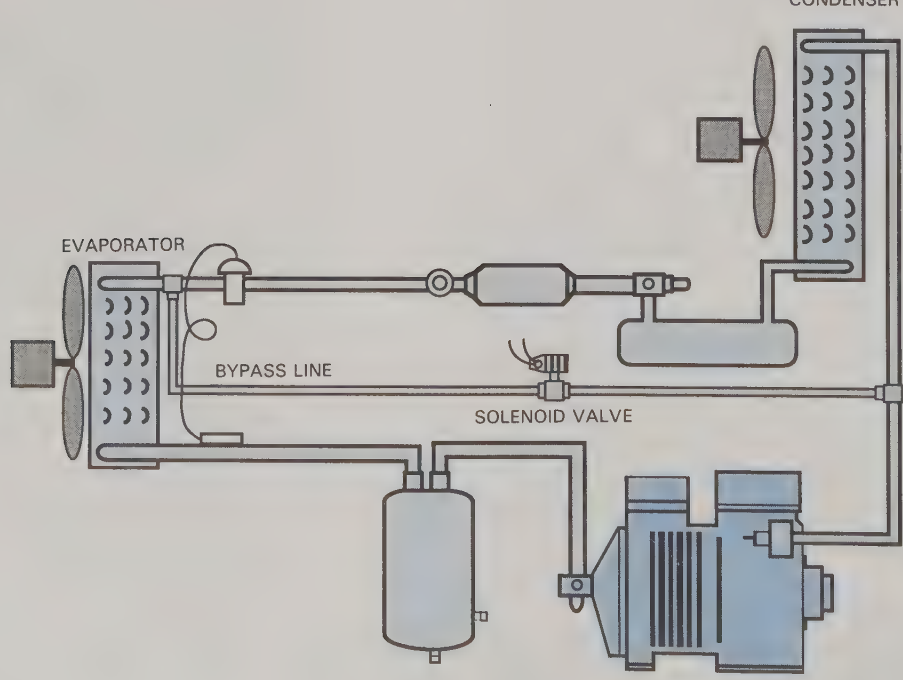


Fig. 24-28. A typical commercial hot gas defrost system. The solenoid valve controls gas flow through the bypass line. A suction accumulator is required in such a system to prevent liquid floodback that could damage the compressor.

fans). The clock does *not* control operation of the condensing unit, since the compressor must operate to produce hot gas for the defrost cycle. See Fig. 24-29. Complete defrost usually occurs within five minutes, with the fail-safe set for 10 to 20 minutes. Hot gas defrost systems may require more frequent cycles, because the length of defrost is determined by the amount of hot gas available.

Troubleshooting

The major disadvantage of hot gas defrost is that the hot gas may condense back to a liquid as it enters the cold evaporator. This presents the possibility of liquid floodback that could damage the compressor. All commercial hot gas defrost systems are provided with a ***suction accumulator*** to prevent liquid floodback during defrost.

Proper hot gas defrost can only be obtained by having sufficient head pressure. A condenser fan cycle control is used to maintain head pressure. This control stops the condenser fan during defrost. Cold ambient temperatures have a drastic effect on hot gas defrost systems, so provision must be made to control the head pressure.

High suction pressure during a run cycle may indicate that the hot gas solenoid valve is leaking. The thermostatic expansion valve desuperheats the hot gas by permitting more liquid to enter the evaporator. This results in high suction pressures and a prolonged run cycle. A leaking solenoid valve may produce a whistling sound, which indicates gas is flowing through the valve seat. Such a leaking valve will permit gas to enter the evaporator during the off cycle. This causes short cycling of the compressor.

To detect a leaking valve, feel the temperature of the hot gas *defrost* line some distance away from the hot gas discharge line. Allow for heat from the hot gas discharge line traveling along the hot gas defrost line. Some solenoid valves have a manual shutoff valve stem for troubleshooting and isolation.

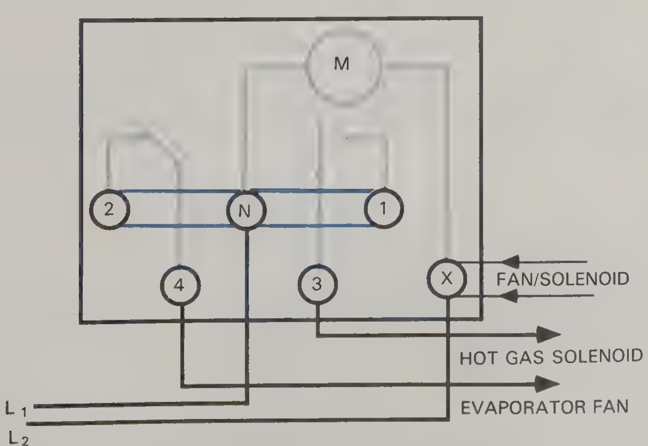


Fig. 24-29. In a hot gas defrost system, the timeclock does not control the condensing unit.

DEFROST CONTACTORS

The contacts on commercial timeclocks are normally rated at 40A, but some electric defrost heaters require higher amperage. Timeclocks are available that have heavier duty contacts rated at 55A per switch. These are lug-type terminals for wire sizes from #4 to #14. See Fig. 24-30. Such heavy-duty timeclocks are available in time-terminated, temperature-terminated, or pressure-terminated models. Operation is identical to timers previously described.

Three-phase systems often use a contactor to control power supply to the heaters. This contactor is located inside the control panel at the condensing unit and is mounted beside the compressor contactor. The timeclock controls both the coil on the compressor contactor and the coil on the defrost contactor. The defrost heater circuit is fused separately. See Fig. 24-31.

MULTIPLEXING

Multiplexing is the term used to describe multiple evaporators connected to one compressor. An example is a row of supermarket display cases. Any number of display cases can be connected to one compressor, but each case must operate at the same temperature. A row of five frozen food cases may be connected to one compressor and another row of five frozen food cases will be connected to another compressor. Multiple dairy cases are connected to one compressor, and multiple meat cases are connected to one compressor.

Space is provided behind the kick-rail (toe plate) of each case for installing one suction line and one liquid

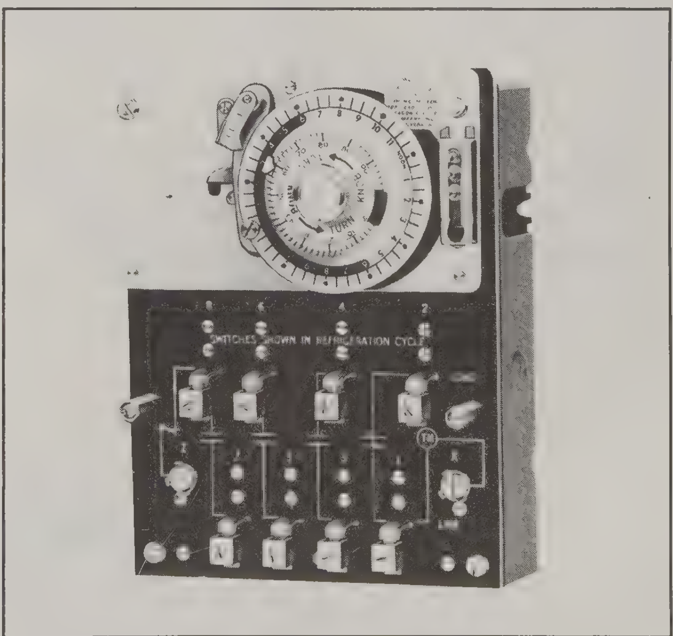


Fig. 24-30. A time-initiated/temperature-terminated timeclock with contacts rated at 55A. The lug-type terminals accept wire sizes from #4 to #14. (Paragon Electric Co.)

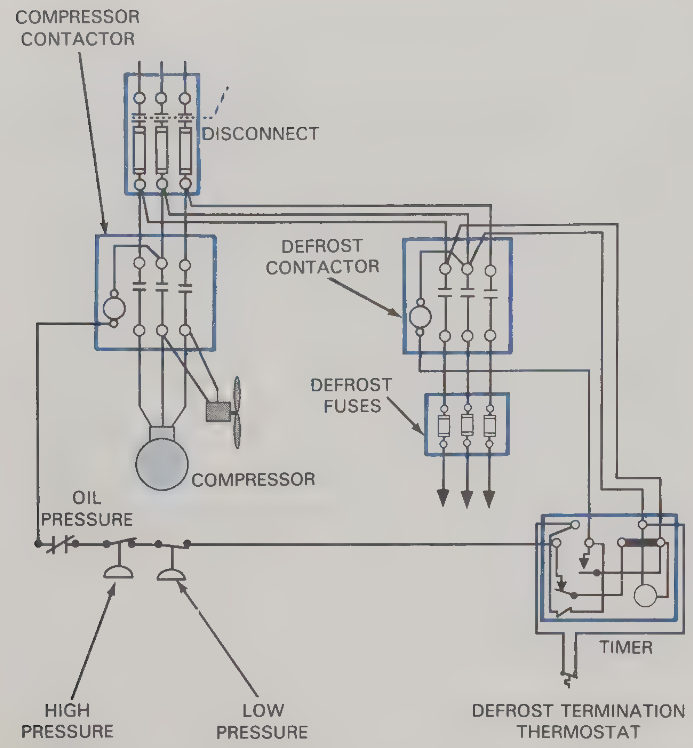


Fig. 24-31. Timeclocks are often used to control several contactors. In this circuit, both the compressor contactor and the defrost contactor are controlled by the timer.

line from the condensing unit. As shown in Fig. 24-32, each case is connected into the suction and liquid lines. Each evaporator has its own thermostatic expansion valve, fans, and defrost heaters. This procedure is equivalent to having one very large evaporator connected to one compressor. To prevent liquid floodback, the correct superheat setting for each expansion valve is critical.

The temperature of multiplexed evaporators is usually controlled by a low-pressure control located at the condensing unit. Sometimes multiple cases are controlled by a single thermostat located in one of the middle cases. Locating the thermostat in a case at either end of the row is not recommended, since an accurate temperature cannot be obtained.

Most display cases have both defrost heaters and special-purpose heaters. The defrost units are long heater rods with round aluminum fins that increase their surface area. More than one heater is often used to accomplish quick defrost. Additional heaters are often used for special purposes. They include the drain pan heater and front flue heater, as shown in Fig. 24-33.

A defrost termination thermostat is located in each case. These thermostats are wired in series, so the defrost cycle cannot end until all thermostats are closed.

Electrical connections for multiplexed systems are accessible in the condensing unit control panel, and in the kick rail under each case. Fig. 24-34 is a complete wiring diagram for a typical multiplexed system.

Troubleshooting

Troubleshooting a multiplexed system is easy because the system will identify the problem. If all cases have the same problem, check the condensing unit. If only one case has a problem, the trouble is inside that case.

For example, a refrigerant leak will affect all cases equally. The problem is found at the condensing unit by checking the sight glass. If one case is suffering from high temperature but the others are operating normally, the problem is found inside that case. This usually involves a plugged condensate drain and a case that is full of ice. The drain must be opened with hot water and then all the ice melted manually before refrigeration is restored.

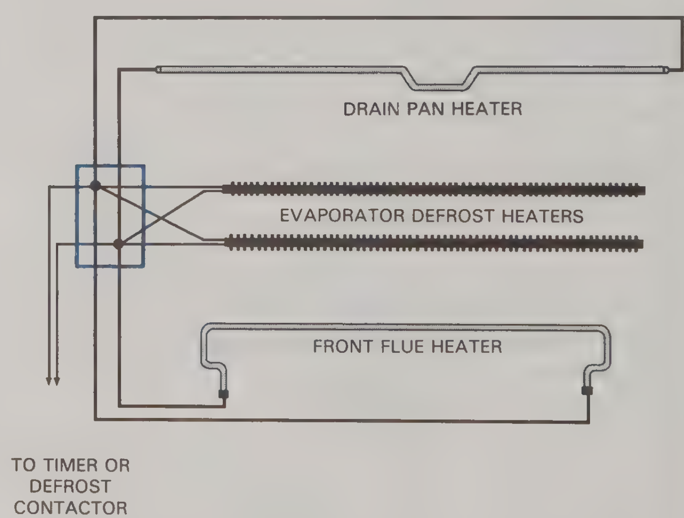


Fig. 24-33. The electric defrost used on multiplex systems often includes both defrost and special-purpose heaters.

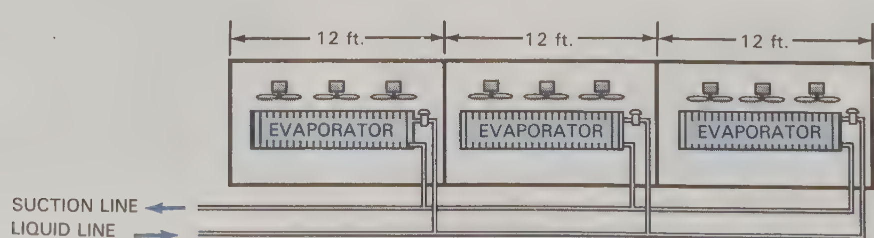


Fig. 24-32. In a multiplexed installation, several display cases or coolers are connected to suction and liquid lines from the same compressor. All cases must be the same temperature.

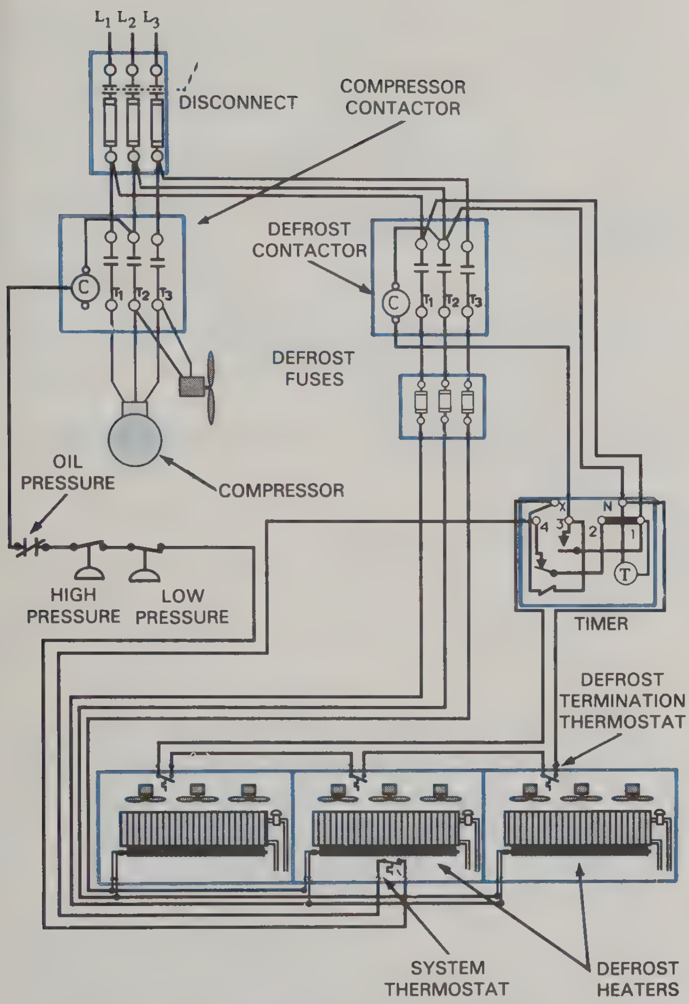


Fig. 24-34. A three-phase multiplexed system with three display cases served by a single compressor and timeclock. Note that the system thermostat is located in the middle case for greater accuracy.

Electrical problems are easily identified at the unit control panel by using step-by-step electrical troubleshooting procedures. A safety control problem will prevent the system from operating. Such problems might be traced to the oil pressure safety control (oil problem), the head pressure safety control (high head pressure), or the low pressure control (a refrigerant leak). Problems may also be traced to the timeclock (defrost problem), fuse (excess amperage flow), or compressor (cycling on the overload).

REVERSE-AIR DEFROST CYCLE

The ***reverse-air defrost cycle*** has recently found popularity in supermarkets. It is an energy saver because warm store air is used to defrost refrigerated food display cases. During defrost, rotation of the evaporator fans is reversed. This reverse airflow causes warm store air to be drawn into the air duct of the case. This warm air is circulated through the evaporator and discharged back into the store. See Fig. 24-35.

A time-initiated/temperature-terminated clock is used for reverse air defrost. The clock shuts off the condensing unit and energizes the coil of a special ***reversing relay*** located on top of each display case. When energized, the relay reverses wiring connections to the evaporator fans and thus reverses rotation. See Fig. 24-36.

The 120V evaporator fans used for reverse-air defrost are special because they have two sets of main windings, with a neutral wire that is common to both windings. Connection of the "hot" wire determines rotation because one winding is clockwise (CW) and the other is counterclockwise (CCW). Only one winding is energized during the run cycle; rotation is CCW. During defrost, the relay disconnects one winding and energizes the other. This reverses rotation to CW.

Defrosting ends when the defrost termination thermostat senses a temperature of about 50°F (10°C). With defrost terminated, the relay contacts switch back to their normal position. This changes fan rotation to CCW and restores the normal airflow pattern. Frequency of defrost should be every eight hours (for example, 6 a.m., 2 p.m., 10 p.m.). with the fail-safe set for 60 minutes.

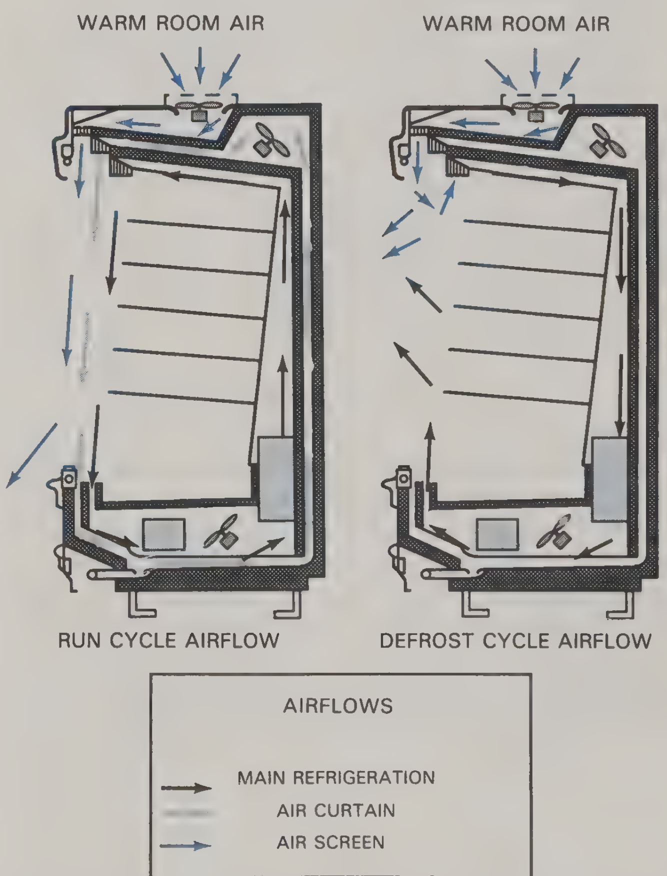


Fig. 24-35. The reverse-air defrost method makes use of warm room air to melt the frost off evaporator coils. A reversing relay changes the direction of rotation of the evaporator fans during the defrost cycle. The air screen and air curtain flows help prevent infiltration of warm air into the refrigerated space.

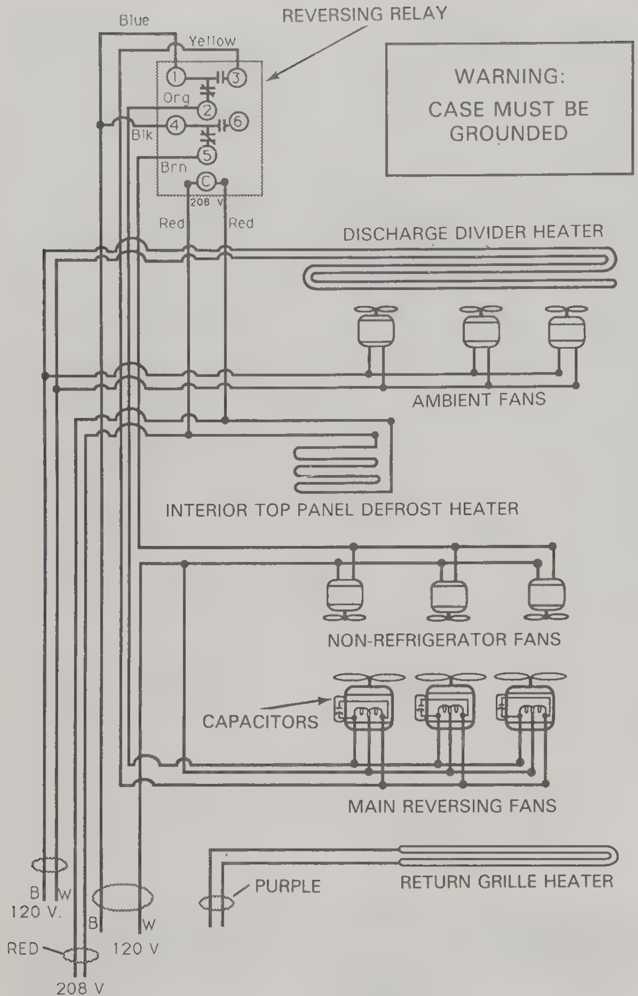


Fig. 24-36. As shown on this schematic, the defrost timeclock controls the reversing relay, which switches between CW and CCW windings of the special evaporator fan motors.

SUMMARY

Various methods and components are used to remove frost accumulation from the evaporator of a refrigeration system. There are five basic types of defrost cycles. The type of defrost system to be used dictates what components are required. Wiring connections and troubleshooting procedures also depend upon the type of defrost.

Various types of defrost timeclocks are used to initiate a defrost cycle, based on time of day. Termination of the defrost cycle can be performed by time, temperature, or pressure. Defrost accessories are often included to make the system more efficient and safe.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Defrost cycles are necessary when evaporator temperature is below ________.
2. Name five types of defrost systems.
3. During a domestic electric defrost cycle, what components are turned off?
4. What does the timeclock control on a domestic hot gas defrost system?
5. During off-time defrost, what components are controlled by the clock?
6. Which defrost timeclocks operate continuously, commercial or domestic?
7. Name the three types of commercial defrost timeclocks.
8. Are pins on the timeclock face used to initiate or to terminate the defrost cycle?
9. True or false? The small dial on the clock face is used to terminate the defrost cycle.
10. Contacts on the fan delay thermostat ________ on a rise in temperature.
11. Contacts on the defrost termination thermostat ________ on a rise in temperature.
12. On commercial systems, the defrost termination thermostat is used to control power supply to the ________.
13. Why is the condenser fan stopped during hot gas defrost?
14. What is the purpose of the defrost contactor?
15. Where are the main suction and liquid lines located on multiplexed display cases?
16. On multiplexed evaporators, the defrost terminator thermostats are connected in ________.
17. On a reverse-air defrost system, which components are controlled by the timeclock?
18. What is special about evaporator fans used in a reverse-air defrost system?
19. True or false? Short, frequent defrost periods are preferred over longer and less-frequent ones.
20. How many wires must be used to properly connect the combination fan delay and defrost termination thermostat?

Chapter 25

GAS HEAT WITH AIR CONDITIONING

After studying this chapter, you will be able to:
- *Identify components of a gas heating system.*
- *Describe the purpose of each gas heating system component.*
- *Discuss proper adjustment techniques for burner flames, fan/limit controls, and heat anticipators in gas heating systems.*
- *Demonstrate how to wire heating and cooling system components.*
- *Describe methods for properly connecting two-speed motors*

NEW WORDS

air duct system
automatic gas valve
blower relay
blower section
clamshells
combination fan/limit control
crossover igniter
draft
draft hood
electrodes
electronic ignition
extended plenum system
fan switch
filter
flue
forced convection
grilles
heat anticipator
heat exchanger
incomplete combustion
limit switch
manifold
mercury
mercury switch
orifice
pilot flame
plenum
primary air
radial piping system
register
return air ducts
secondary air
supply air ducts
thermocouple
thermostat
thermostat override

FORCED CONVECTION SYSTEMS

Most residential heating and cooling systems are ***forced convection*** types. "Total comfort" is achieved by automatically controlling air circulation (movement), temperature (heating and cooling), filtration (cleaning), and moisture content (humidity). During its operating cycle, a forced convection system heats or cools air and directs it to all areas of the conditioned space. See Fig. 25-1. The furnace can be located in a basement, attic, crawl space, or utility closet. Basic components that are common to residential forced convection ("forced air") heating and cooling systems include air ducts, burners, blower, filter, evaporator, condensing unit, and thermostat.

The furnace contains a blower section (motor and fan) used to circulate air in the home. Separate air ducts (metal tubes) are used to control air movement to and from the furnace.

During the cooling season, heat and humidity are removed from the air. The cooling system is an outdoor condensing unit with an evaporator located in the furnace ***plenum*** (supply air chamber). An air-sensitive thermostat is centrally located in the conditioned space to control system operation. The thermostat is designed to prevent heating and cooling systems from operating at the same time.

AIR DUCT SYSTEM

The ***air duct system*** is the network of tubes that is used to control airflow to and from the conditioned space. Ducts carrying air *to* the conditioned space are called ***supply air ducts.*** The ducts bringing air *back* to the furnace for reconditioning are called ***return air ducts.*** A blower section (fan and motor) is located inside the

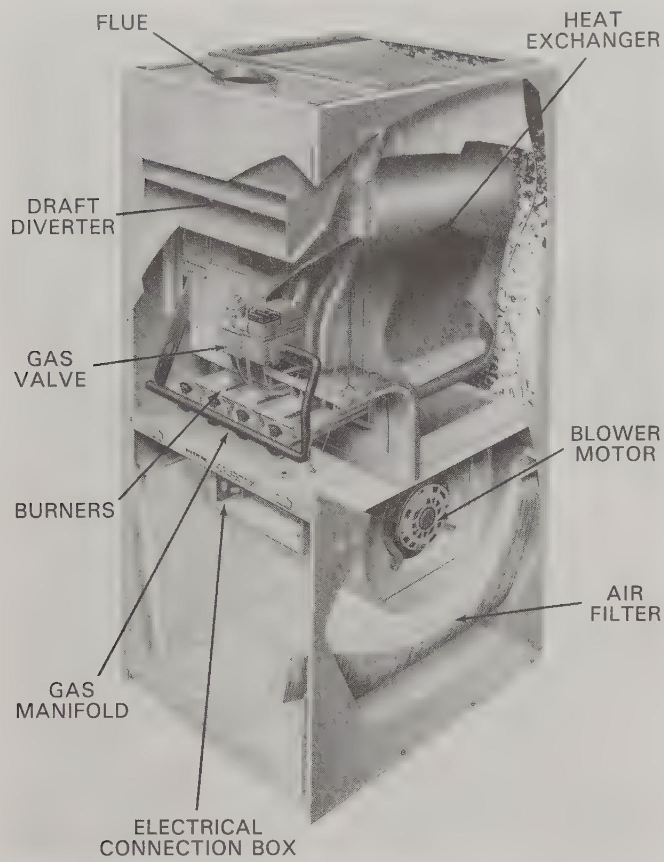


Fig. 25-1. A cutaway view of a typical gas-fueled forced-air furnace. With the addition of an evaporator coil and a separate condensing unit, the same equipment can also be used for cooling. (Lennox)

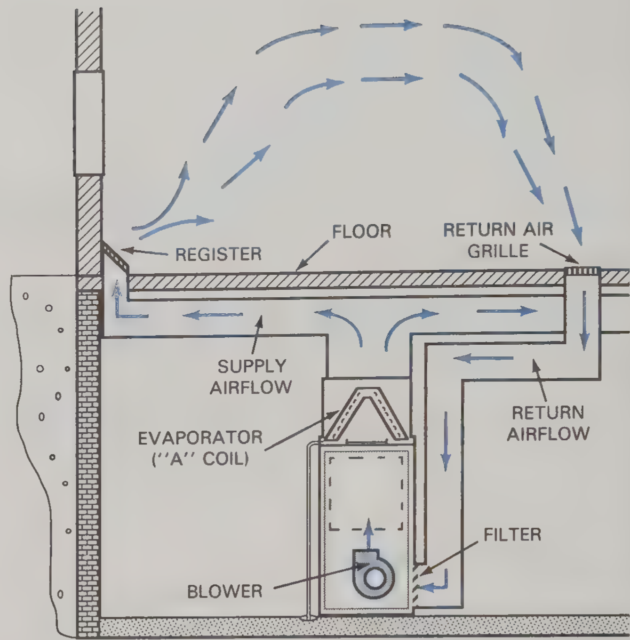


Fig. 25-2. The air duct system consists of supply air ducts carrying conditioned air to the space being heated or cooled, and return air ducts that move room air back to the furnace to be heated or cooled again.

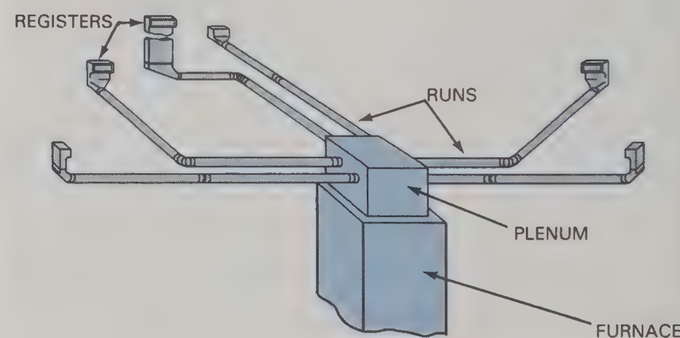


Fig. 25-3. In a radial piping system, round ducts extend directly from the supply plenum to each register. The furnace must be centrally located to use this system effectively.

furnace and provides the forced airflow through the furnace and air ducts. See Fig. 25-2.

Ducts are commonly made of galvanized sheetmetal, but aluminum, plastic, and fiberglass also are used. Ducts are either round or rectangular in shape, and can be rigid or flexible. The tubes are often insulated (inside or outside) to reduce heat transfer and control noise. All duct connections should be airtight.

The supply plenum is a sheetmetal chamber (box), located on the furnace outlet, that feeds the supply air ducts. The air conditioning evaporator (often called an "A" coil, because of its shape) is located inside this plenum. The return air plenum is another sheetmetal chamber located at the furnace air intake. Return air ducts are connected to this plenum.

Radial piping system

A ***radial piping system*** uses round pipe runs that extend from the supply plenum to each ***register*** (supply air outlet), Fig. 25-3. This system is economical and easy to install. It is most practical in homes where the furnace is centrally located and runs can be installed in an attic or crawl space. The radial piping duct system is not practical, however, for homes that are long or odd-shaped.

Extended plenum system

The ***extended plenum system*** combines rectangular duct with round duct. Rectangular duct is used to extend the plenum outward from the furnace as needed, then round pipe is run at a right angle from the extended plenum to each outlet. See Fig. 25-4. This system makes it possible to run the round pipes between the floor joists, since they are running in the same direction. In a basement installation, this plenum system will provide more headroom than suspending the pipes below the joists.

Outlets and inlets

Supply air is released through outlets called registers or diffusers. Registers deliver air in a concentrated flow pattern, while diffusers provide wider, fan-shaped patterns. See Fig. 25-5.

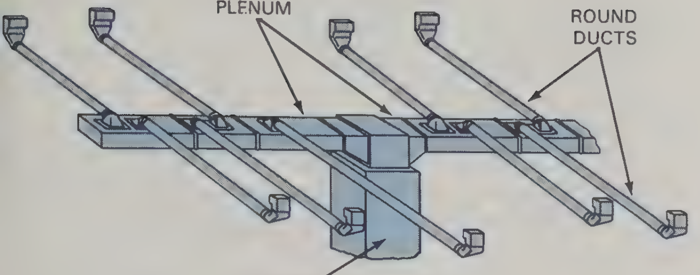


Fig. 25-4. The extended plenum is used for long or odd-shaped houses. An important advantage is the capability of running the round ducts in the spaces between floor joists.

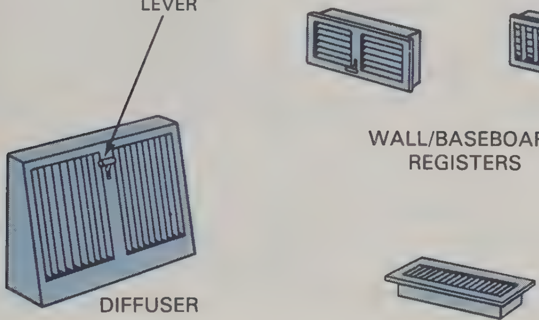


Fig. 25-5. Registers and diffusers are used to supply conditioned air to a confined space. Some adjustment to the amount of airflow is possible. For most effective air movement, they are usually positioned on the outside wall of the room.

Outlets may be located in the floor, wall, or ceiling. Outlets are positioned along outside walls of the house to provide proper air circulation and prevent unwanted drafts. At least one outlet is provided in every room to be heated or air conditioned. Most registers and diffusers contain an adjustable damper for controlling volume of the airflow.

Inlets for return air, Fig. 25-6, are called ***grilles.*** Grilles are nonadjustable, since return airflow to the furnace must be unrestricted. Grilles are normally centrally located on or next to an inside wall. This makes it necessary for conditioned air from a register to flow across the room before entering the grille.

BLOWER SECTION

The ***blower section*** is located inside the furnace cabinet. The blower section consists of a motor and centrifugal (squirrel-cage-type) fan. The fan draws air from the return air ducts and forces it through the furnace for treatment (heating or cooling). The treated air then is pushed through the supply air ducts to individual rooms. There are two types of blowers, belt drive and direct drive. See Fig. 25-7.

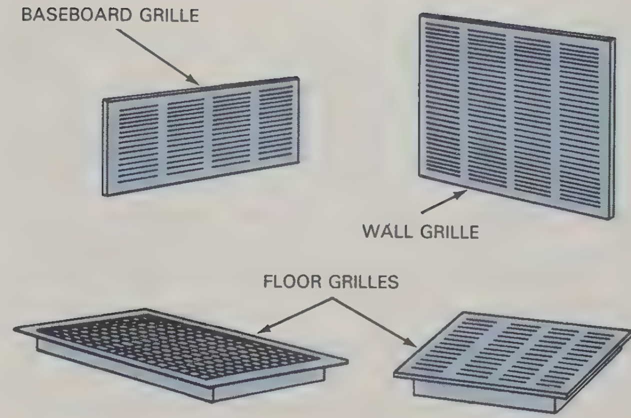
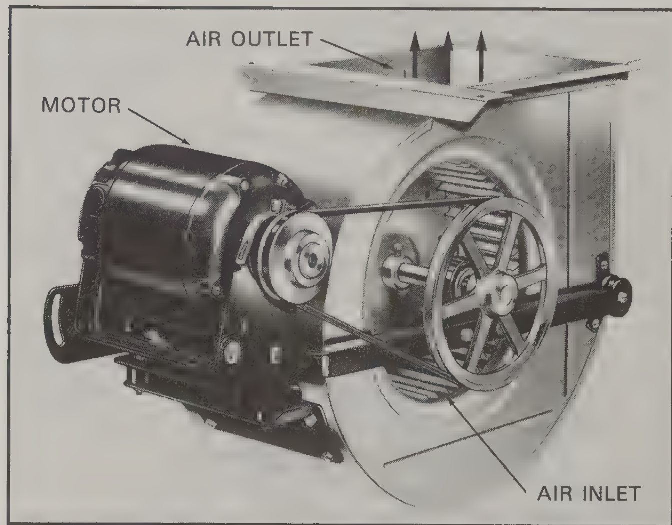
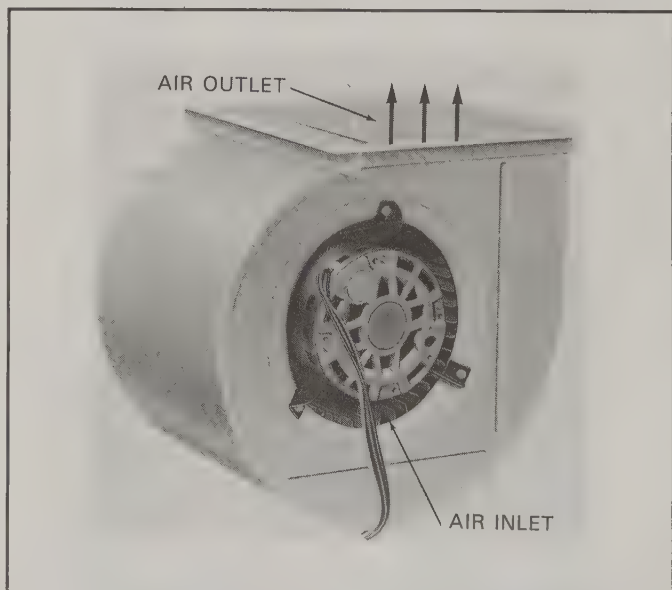


Fig. 25-6. Return air grilles are nonadjustable. They are usually positioned on an inside wall or in the floor next to an inside wall.



A



B

Fig. 25-7. Furnace blowers. A–Belt-drive blower. B–Direct drive blower. (Lennox)

Filter

A *filter* is a cleaning device used to capture dust, lint, dirt, and other impurities from the circulating airstream. The filter is located in the return air side of the blower section. A fiberglass medium is commonly used as a screen for cleaning the air before it enters the blower. Filters should be cleaned or replaced regularly, since a dirty filter reduces system airflow and thus, greatly reduces system capacity. Dirty filters can cause the furnace to overheat.

Many filters are disposable, consisting of a rectangular fiberglass screen in a cardboard frame, Fig. 25-8. Disposable filters are available in many different sizes. The filter should be sized to fit completely across the incoming airstream. Arrows on the filter frame indicate proper direction of airflow. When the filter becomes dirty, it should be replaced.

Some nondisposable filters use a screening medium encased in a metal frame. When this filter becomes dirty, it may be cleaned by washing or vacuuming before reuse.

Never operate the system without a filter. Dirt and lint will quickly plug ventilation openings of the fan motor, causing it to overheat. Dirt will also gather on the evaporator, greatly reducing airflow. Cleaning the evaporator is a difficult and time-consuming task that can be avoided by proper filter cleaning and replacement. Furnace air filters should be cleaned or replaced before each heating or cooling season. Unfortunately, this "ounce of prevention" is often neglected, leading to the need for costly evaporator cleaning.

HEATING SECTION

Gas-fueled furnaces rely on combustion (burning of fuel) to generate usable heat. The combustion process produces waste gases such as carbon dioxide, water vapor, and small amounts of other chemical compounds. ***Incomplete combustion*** may produce such substances as carbon monoxide, aldehydes, and soot, which are dangerous to human health. Gases and other waste products resulting from combustion *must* be properly vented to the outdoors.

The heating section of furnace that is fueled by natural gas or liquefied petroleum (LP) gas consists of burners, a steel ***heat exchanger,*** and a venting system. The heat exchanger is usually divided into sections called ***clamshells***. Burners fit into special chambers that are built into the bottom of the heat exchanger. See Fig. 25-9.

Upon a call for heat from the thermostat, a gas valve is energized (opened), allowing gas to flow to the burners. The gas is ignited and the flame warms the heat exchanger. Hot waste gases from combustion travel up through the inside shell, collect at the top, and are directed to a vent. The vents are connected to a special box called a ***draft hood*** or diverter. A vent pipe (***flue***) is connected from the diverter box to the chimney. See Fig. 25-10.

The heat exchanger clamshells are designed to maintain separation of the recirculating room air from combustion gases. The blower forces recirculated room air around and between the heat exchanger shells. The air is heated as it touches the hot surfaces of the shells. Heated air then travels from the heat exchanger to the supply air plenum and is delivered to living spaces. Most gas furnaces are designed for about a 60°F (33°C)

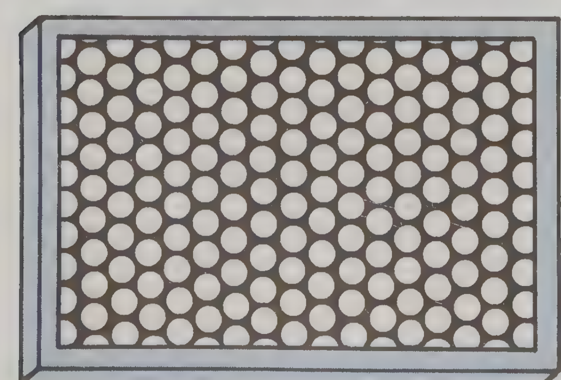


Fig. 25-8. A disposable filter is usually made of fiberglass attached to a cardboard frame. Filters should be replaced on a regular basis to avoid restricting airflow.

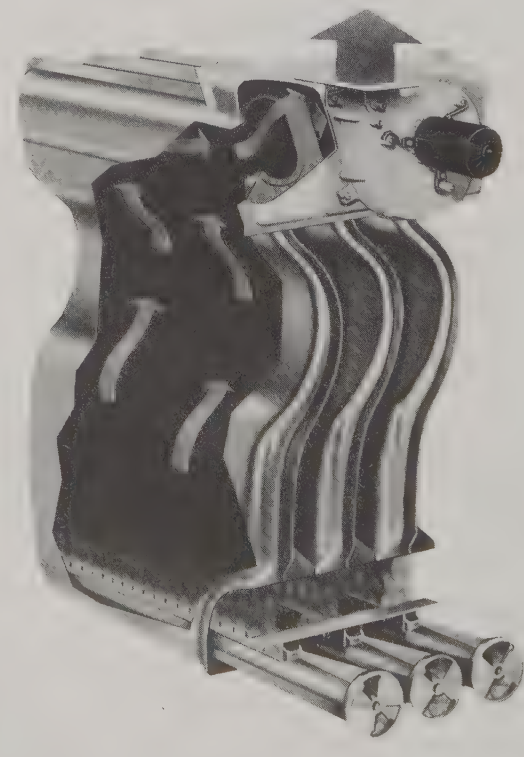


Fig. 25-9. The heating section of a gas furnace includes burners built into the bottom of the heat exchanger and a venting system for the waste products of combustion. (Lennox)

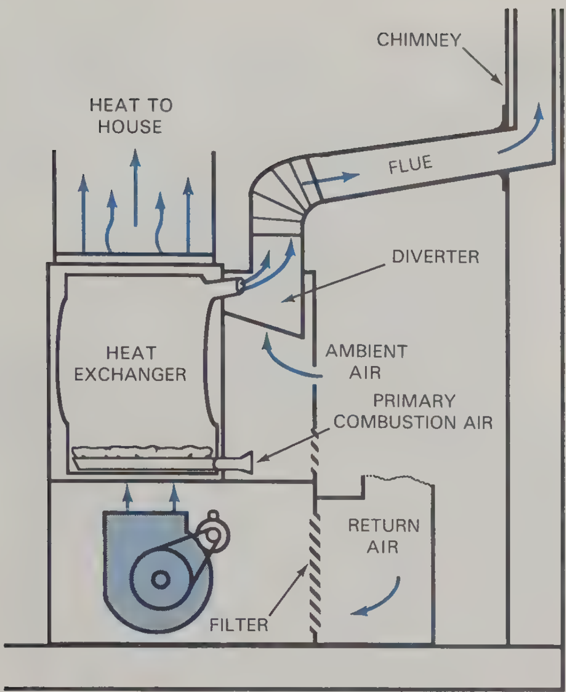


Fig. 25-10. The heat exchanger transfers heat from combustion gases to recirculated room air, while keeping the two separated. Hot waste gases are drawn up the flue and out the chimney.

rise in the temperature of air crossing the heat exchanger. If entering air is 70°F (21°C), exiting air will be about 125°F to 130°F (52°C to 54°C).

GAS BURNERS

The number of burners in a furnace will vary with furnace size. Gas burners vary in style and shape, but essentially work the same way: upon a call for heat, a mixture of atmospheric air and gas enters the burner and is ignited on the surface of the ports.

It is necessary to provide both primary and secondary air to the burner. See Fig. 25-11. ***Primary air*** is drawn into the burner by the jet of gas as it enters. It is mixed thoroughly with gas inside the burner before delivery to the ports. ***Secondary air*** is drawn into the burner chamber after ignition of the flame. Natural convection (the rising of less-dense hot air) creates a ***draft,*** or air movement, into the burner chamber, up through the heat exchanger, and out the flue. Primary air is rarely sufficient for complete combustion. Secondary air provides the additional air for complete combustion.

The amount of primary air is controlled by small adjustable shutters located at each burner inlet. Secondary air cannot be controlled. A yellow gas flame indicates poor combustion. A blue flame indicates good combustion. Addition of secondary air results in a blue flame that is smaller, faster-burning, and has a higher temperature than a yellow flame.

Gas valve and manifold

An ***automatic gas valve,*** Fig. 25-12, is used to start and stop flow of gas to the burners. The automatic gas valve is connected to a pipe, called a ***manifold,*** that distributes gas to the burners through an ***orifice*** (outlet hole) in each burner.

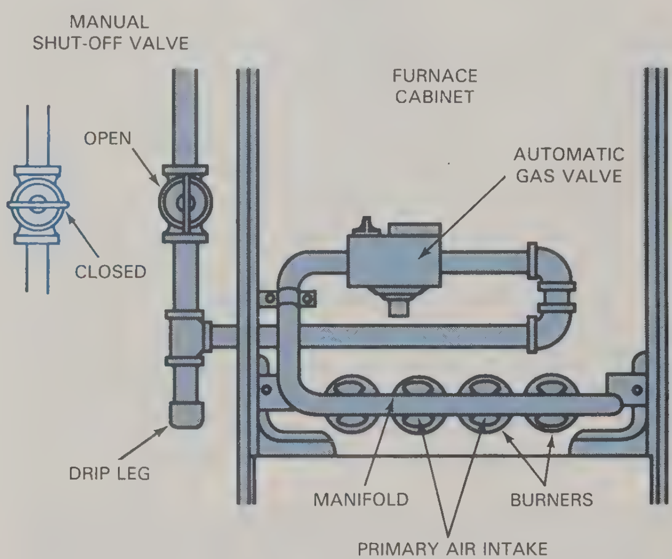


Fig. 25-12. The automatic gas valve controls flow of gas from the supply to the manifold and burners. A manual shut-off valve is usually located at the point where the supply enters the building. The automatic valve includes a solenoid operated by the system thermostat.

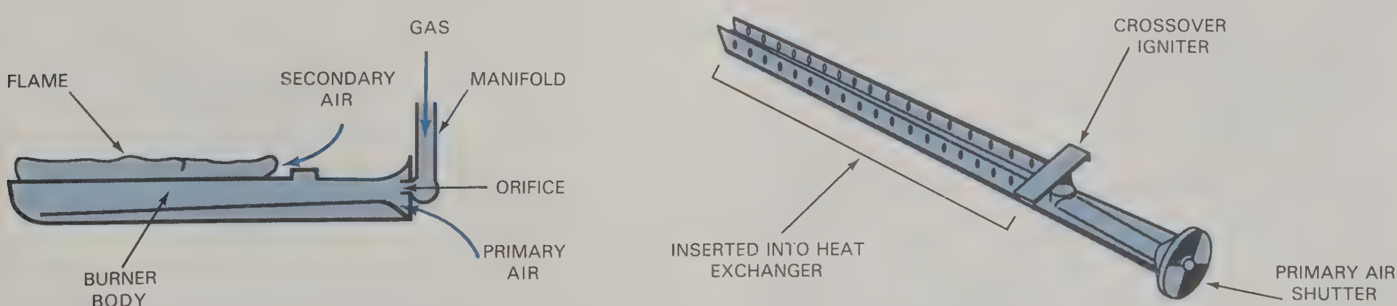


Fig. 25-11. Burners combine air and gas into a mixture that can be burned in a furnace. Primary air is drawn into the burner body by the flow of incoming gas from the gas manifold. Secondary air is drawn into the burner chamber by natural convection. Primary air is adjusted by rotating a shutter on the burner body.

The gas valve contains a 24V solenoid valve. When the solenoid coil is energized by the thermostat, the valve is open and gas flows through to the burners. See Fig. 25-13. When the coil is deenergized, the gas valve closes and the burner flame goes out. A room thermostat controls electrical power supply (24 volts) to the gas valve solenoid.

Most gas valves are combination valves, which include such features as manual shutoff, pilot light safety control, and an internal gas pressure regulator. See Fig. 25-14. A manually operated knob on top of the valve has three positions:

- ON (The normal operating position. Opening and closing of the gas valve solenoid is electrically controlled by the thermostat at terminal W.)
- OFF (Used to manually shut off gas supply to the furnace.)
- PILOT (Used to light the pilot without opening the main valve. Depressing the knob in this position permits gas flow only to the pilot valve.)

Pilot flame. The ***pilot flame*** is a small gas flame used to ignite the flame on the main burners. A constantly burning pilot is called a "standing pilot." Gas flow to the main burners cannot be allowed when the pilot flame is out (not lighted). Without a pilot flame, gas would collect inside the furnace and eventually explode when exposed to a spark or flame.

Thermocouple. A *thermocouple*, Fig. 25-15, is a safety device that prevents the main gas valve from opening if there is no pilot flame. The thermocouple converts heat energy to electrical energy. The sensing element of the thermocouple is positioned within the pilot flame. Heat from the flame generates a tiny amount of electricity (measured in millivolts) in the thermocouple. This electrical energy is conducted to the main combination gas valve as a signal that a pilot

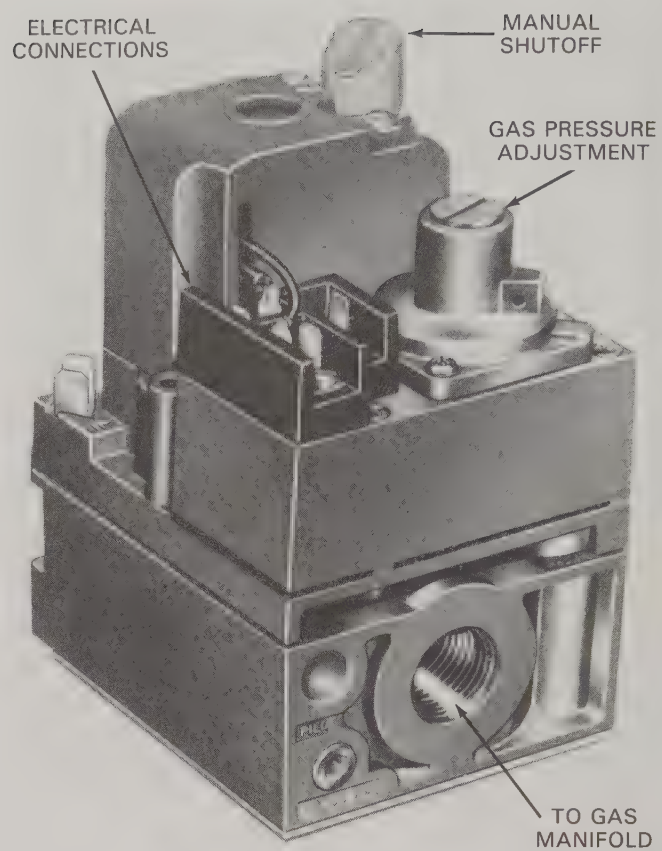


Fig. 25-14. A combination gas valve with manual shutoff and an internal pressure regulator. (Honeywell)

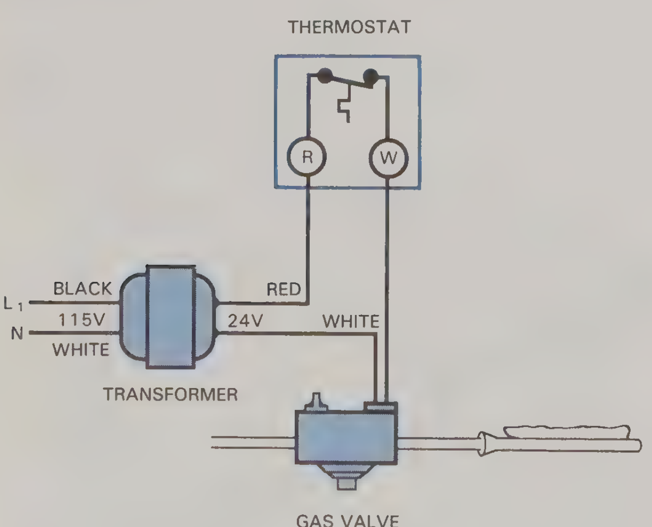


Fig. 25-13. The system thermostat controls power to the gas valve solenoid. The control circuit operates on 24V, opening and closing the solenoid valve to regulate gas flow to the burners.

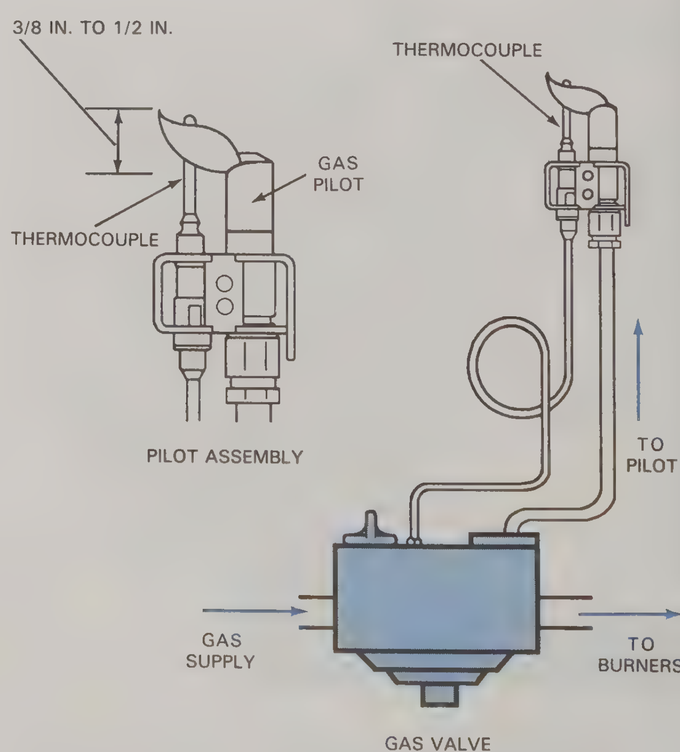


Fig. 25-15. The thermocouple is a safety device that confirms existence of a pilot flame. Without the signal generated by the thermocouple, the gas valve will not open to supply fuel to the burners.

flame is available. If the pilot flame goes out, the electrical signal is not generated and the main gas valve cannot open. This safety feature prevents gas flow to the burners when the pilot flame goes out.

The pilot light should have a soft blue flame and envelop (cover) between 3/8 in. to 1/2 in. (10 cm to 13 cm) of the thermocouple's tip (hot junction). Proper positioning of the thermocouple within the pilot flame is critical. The pilot flame is adjustable by a special screw included on the combination gas valve. Remember: the gas valve cannot open unless the thermocouple generates the proper signal. Minimum acceptable DC voltage is 18mV.

Crossover igniter. A *crossover igniter* is used to ignite several main burners from a single pilot flame. The crossover igniter is a slotted length of metal that acts as a bridge between burners. Gas flowing to the main burners also travels through the igniter slots until it comes in contact with the pilot flame. Proper positioning of the burners will correctly align the crossover igniter. A poorly positioned burner will cause noisy and delayed ignition. See Fig. 25-16.

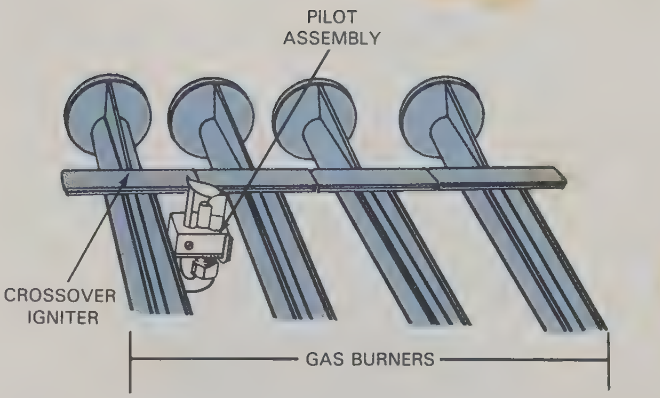


Fig. 25-16. A crossover igniter serves as a bridge between burners, allowing a number of them to be ignited by a single pilot flame.

Electronic ignition. An *electronic ignition* ("spark ignition") system saves fuel by eliminating the continuously burning pilot flame. The pilot flame is ignited by an electric spark and burns only upon a call for heat. If the pilot flame blows out, the system will automatically relight it if the call for heat still exists. The pilot assembly, Fig. 25-17, consists of a pilot burner, a spark electrode, and a sensing probe.

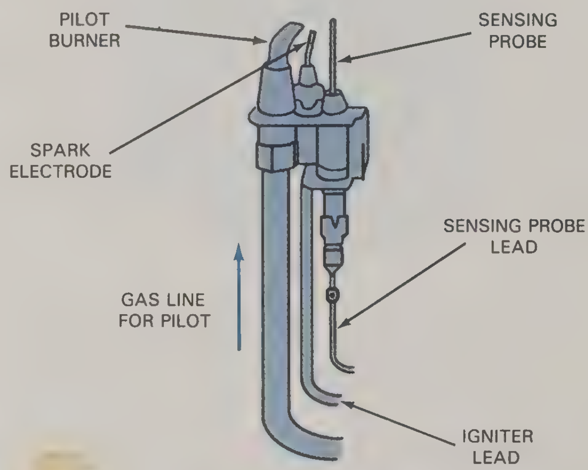


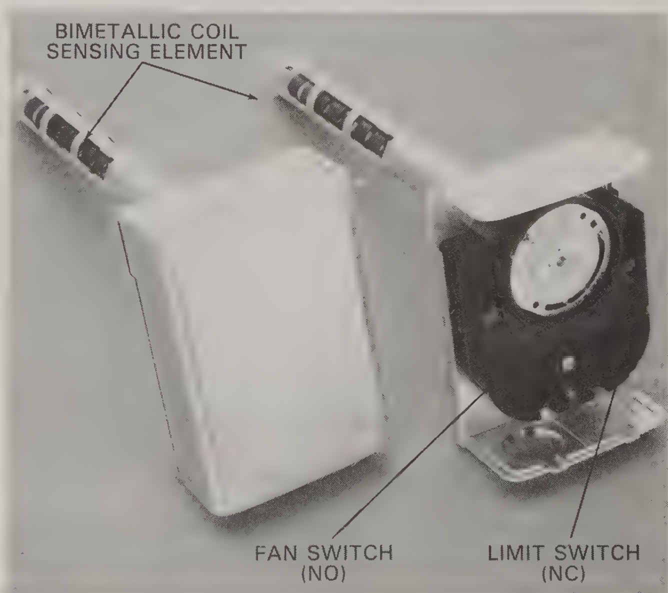
Fig. 25-17. When the thermostat calls for heat, the electronic ignition system lights the pilot, which in turn, lights the main burners. The electronic system eliminates the fuel cost of a constantly burning pilot.

When the thermostat calls for heat, the spark electrode automatically lights the pilot flame. The sensing probe (thermocouple) then proves the presence of the pilot flame. Once the pilot flame is proven, the spark electrode is deenergized and the main gas valve is opened. The main burners are then ignited by the pilot flame. When the thermostat is satisfied and opens its switch, the main gas valve is turned off. This stops flow of gas to both the burners and the pilot flame.

COMBINATION FAN AND LIMIT CONTROL

The *combination fan/limit control* serves a dual purpose. It controls operation of the blower motor and provides safety protection against overheating of the furnace. See Fig. 25-18. This control contains two electrical switches, one normally open (NO) and one normally closed (NC). Movement of a coiled bimetallic strip controls operation of the switches.

The bimetallic coil is inserted into the heat exchanger area to sense furnace temperature, Fig. 25-19. Heat causes the coil to twist in a circular movement. This movement controls the NO and NC switches. The amount of heat necessary to activate the switches is adjustable. These adjustments are made on a calibrated dial located on the control face, Fig. 25-20.



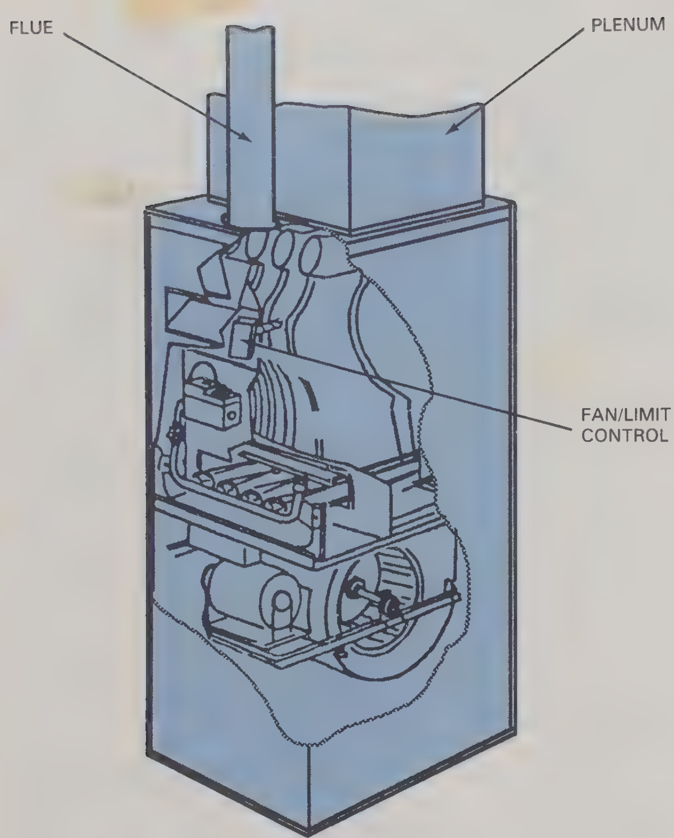


Fig. 25-19. The fan/limit control is positioned with the sensing element inserted in the heat exchanger to sense furnace temperature.

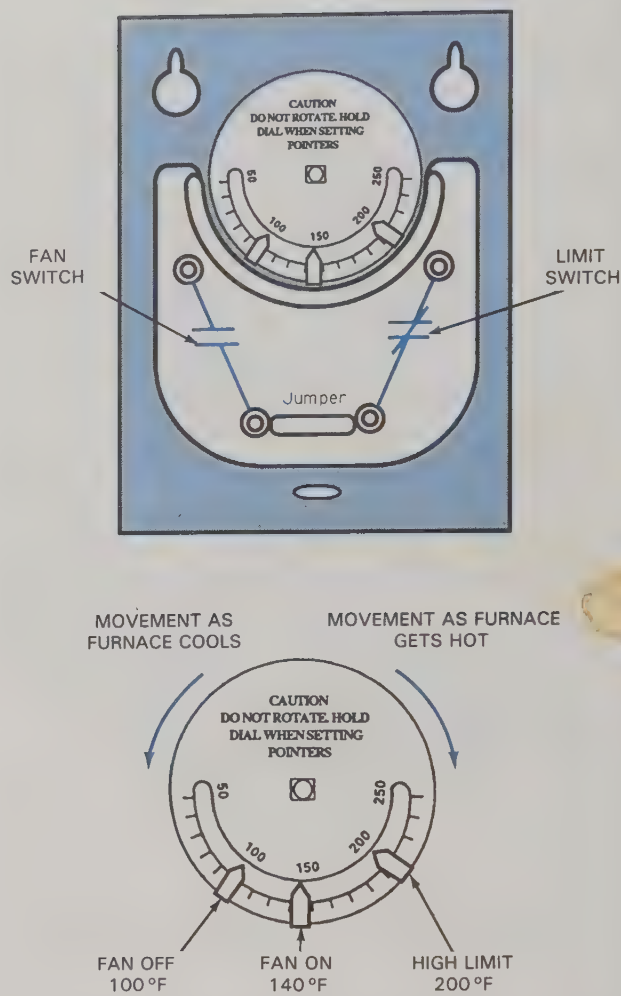


Fig. 25-20. A calibrated dial located on the face of the fan/limit control is used to set the fan on, fan off, and high limit temperatures. As the bimetallic coil sensing element is heated or cools, it twists one way or the other, rotating the dial.

Fan switch (normally open)

The normally open switch, used to operate the blower motor, is called the ***fan switch.*** When the furnace temperature reaches a selected setting on the dial face (usually 140°F or 60°C), the switch closes and turns on the blower motor. Air is then pulled from the living space, forced through the heat exchanger where it is heated, and returned to the living space. This movement of air through the heat exchanger causes the furnace temperature to drop to about 125°F (52°C), where it remains during the heating cycle.

When the heated space reaches the desired temperature (typically 72°F), the thermostat contacts open and stop current flow to the gas valve. This causes the burner flame to go out, but the blower motor continues to run because the furnace is still hot. Cooling of the furnace causes the bimetal to twist in the opposite direction. The fan will keep running until the furnace temperature drops to about 100°F (38°C), when the fan contacts reopen and stop the blower motor. See Fig. 25-21.

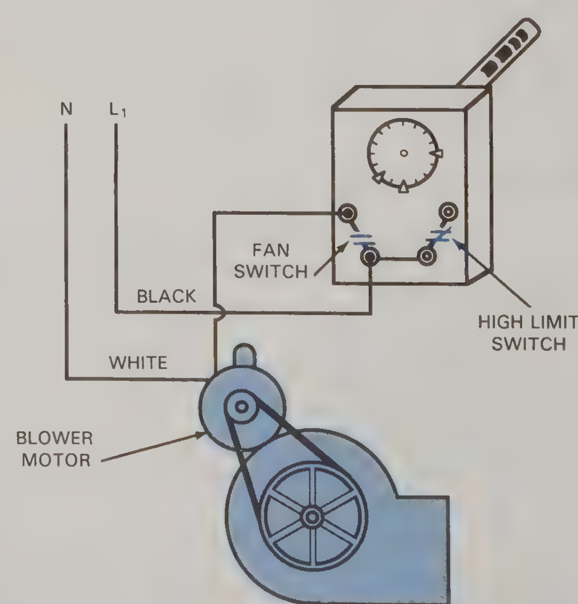


Fig. 25-21. The fan switch controls the blower motor during the heating cycle.

Limit switch (normally closed)

A ***limit switch*** is a safety device that cuts off the power supply if the furnace becomes overheated. The furnace may overheat due to lack of airflow by fan motor failure, a broken V-belt, a dirty filter, or failure of the fan switch contacts. The limit switch, which is

normally closed, will open if the furnace temperature reaches about 200°F (93°C).

The limit switch must be connected so that it will cut off power supply to the gas valve (and thus turn off the burners) if the furnace overheats. One of two methods can be used to connect the limit switch. It can be connected in series with power supply to the primary of the low voltage transformer, as shown in Fig. 25-22. This method cuts off power to the entire low voltage circuit, which supplies 24V power to the gas valve.

The other method (also shown in Fig. 25-22) places the limit switch in the 24V circuit supplying power to the gas valve. Either method is acceptable. The combination fan/limit control has a factory installed jumper between the fan switch and the limit switch. This jumper remains in place when using the limit switch to disconnect line voltage to the transformer. The jumper must be removed when connecting the limit switch in the 24 volt circuit to the gas valve.

LOW-VOLTAGE HEATING THERMOSTAT

A *thermostat* is a switch that opens and closes according to changes in temperature. The thermostat is located within the living space where temperature is being controlled. It turns heating and air conditioning equipment on and off automatically to maintain specific temperatures within that space. Only one thermostat is used and it must be located where it can sense proper temperature. Cold walls and doorways must be avoided.

Thermostats for heating and cooling are different from those used for refrigeration. They are designed to operate on 24 volts, because they are often located considerable distance from the heating and cooling equipment. The low voltage permits the use of small wires which are easily hidden from view. The 24V system has several other advantages: it produces very little arcing of the switch contacts, which results in long switch life, and both shock and fire hazards are virtually eliminated.

Power is supplied to the thermostat by the secondary winding of the transformer. A red wire is used to connect power supply from the transformer secondary (24V) to terminal R on the thermostat. The thermostat then becomes an automatic switching device that will control the 24V power supply to various electrical components.

Thermostat construction

Most thermostats are constructed with a small bimetallic (brass and invar) element that is shaped in a coil. This coil is extremely sensitive to small changes in temperature. The end of the coil at the center of the spiral is anchored. As the coil winds and unwinds according to small temperature changes, the outside end moves in an arc. See Fig. 25-23.

Mercury switches

A ***mercury switch*** consists of two wire ends (***electrodes***) that are exposed inside one end of a glass tube. The glass tube is mounted on the free end of the bimetallic element. A drop of the metallic element ***mercury***,

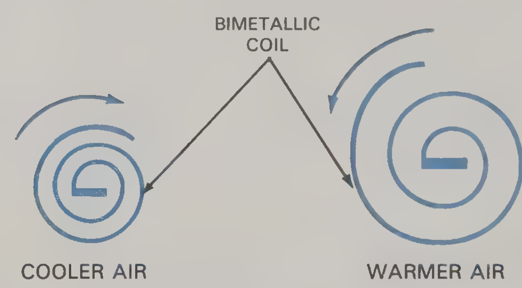


Fig. 25-23. The coil is anchored at the center of the spiral, so the outside end moves in an arc as the temperature changes. As the air cools, the coil becomes tighter; as the air warms, it becomes looser.

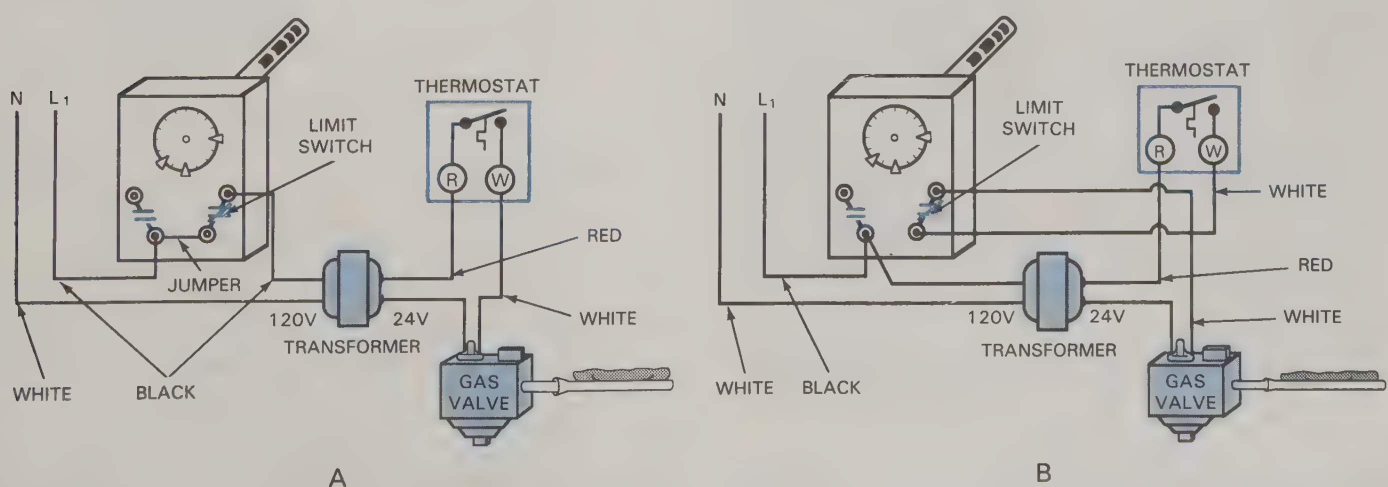


Fig. 25-22. Two methods of connecting the limit switch. A–In the high-voltage method, the switch is in series with power supply to the transformer. If the switch opens, the entire 24V circuit is deenergized. B–In the low-voltage method, the switch is in the 24V circuit supplying current to the gas valve.

which is a liquid at room temperature, is contained in the glass tube. Whenever the tube is tipped, the mercury flows to its lowest end.

As shown in Fig. 25-24, when the mercury is at the end opposite the electrodes, the switch is open. No current can flow from one electrode to the other. When the tube is tipped in the other direction, the mercury flows to the electrode end. Mercury is an excellent conductor of electricity. By contacting both electrodes, the mercury will complete an electrical circuit from one electrode to the other. The switch is now closed.

The glass tube is actually shaped like a bean, with a slight hump in the center. The mercury must run over this hump when the bulb is tilted. It requires a greater degree of tilt to move the mercury from one end to the other. This prevents rapid cycling due to vibration (called "chatter").

Thermostat override

When the furnace continues to deliver heat after the thermostat is satisfied, it is called overriding the thermostat, or ***thermostat override.***. When the room temperature has reached the desired level, the thermostat opens and shuts off the gas valve. The blower motor, however, continues to run and deliver heated air until the furnace cools down to 100°F (38°C). This causes the room temperature to become too high.

Heat anticipator

To compensate for thermostat override, a small resistance heater (called the ***heat anticipator***) is mounted inside the thermostat close to the bimetallic coil. Current flow through this heater during the heating cycle warms the bimetal, Fig. 25-25. This additional heat causes the thermostat switch to open *just before* room temperature reaches the desired level. The furnace blower continues to operate and cool the furnace down to 100°F. This additional heat brings the temperature of the living space up to the desired temperature level. Thermostat override has been overcome and room temperature is controlled within plus or minus 1°F.

The heat anticipator is energized when the furnace is operating in the heating mode. This small heater is factory connected between the bulb electrode and terminal W (the heat terminal) on the thermostat. This places the heat anticipator electrically in series with the gas valve in a gas furnace, with the primary control in an oil furnace, or with the heat sequencer in an electric furnace.

Heat anticipator adjustment. Some heat anticipators have a fixed resistance, while many are adjustable. See Fig. 25-26. The adjustable heat anticipator has a slide adjustment with a pointer and a scale that is calibrated in tenths of a ampere. The pointer is moved to the scale reading that agrees with the amperage flow to the gas valve. This low amperage draw can be measured with an amprobe and a multiplier.

The amperage draw by the gas valve is stamped on the valve body. The heat anticipator should be set to this amperage to control override. For example, if the draw of the circuit is 0.45 amps, the anticipator pointer must be moved to point at 0.45 on the scale. This provides the necessary additional heat for precise control of room temperature.

Fig. 25-27 provides a schematic and pictorial wiring diagram for a complete gas heating system that provides automatic control and proper safety.

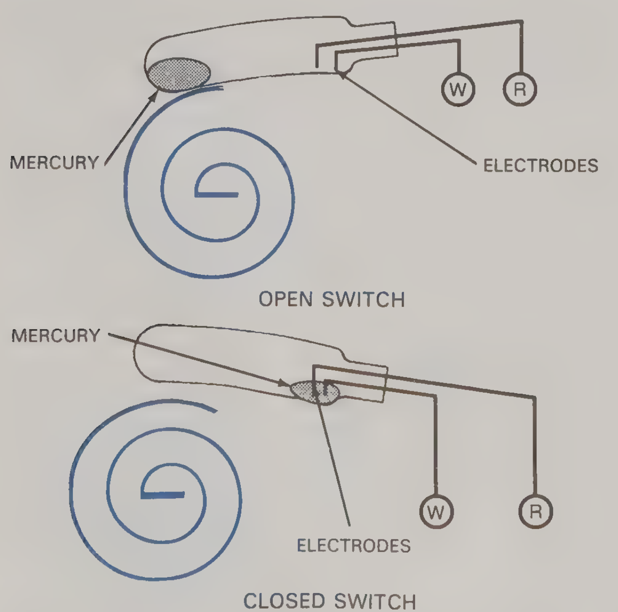


Fig. 25-24. Tilting of the glass tube by movement of the bimetallic element inside the thermostat allows a drop of mercury to open or close the switch controlling heating or cooling operations.

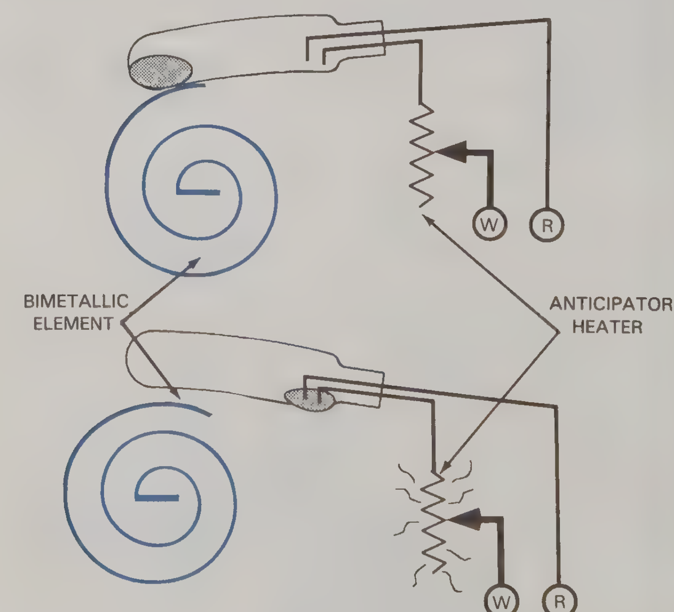


Fig. 25-25. The heat anticipator prevents furnace "override" at the end of the heating cycle. It warms the bimetallic element so that the switch actually closes slightly before the room temperature reaches the setpoint.

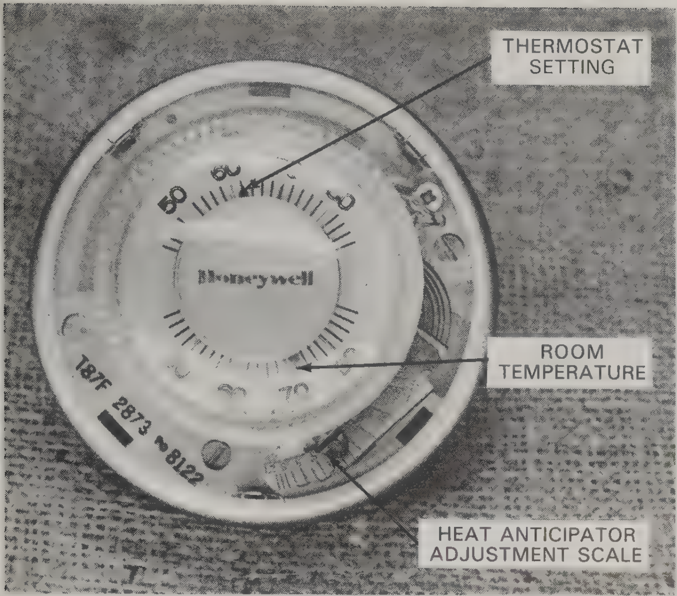


Fig. 25-26. The scale and pointer for an adjustable heat anticipator can be seen by removing the thermostat cover. The pointer should be on the scale marking that matches the amperage draw of the gas valve.

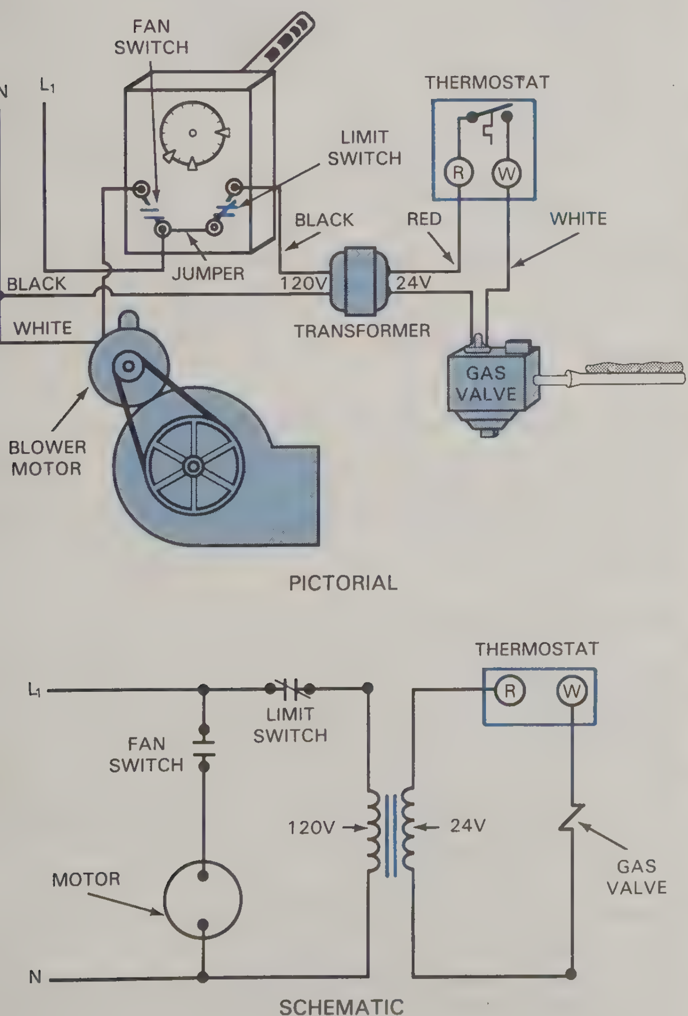
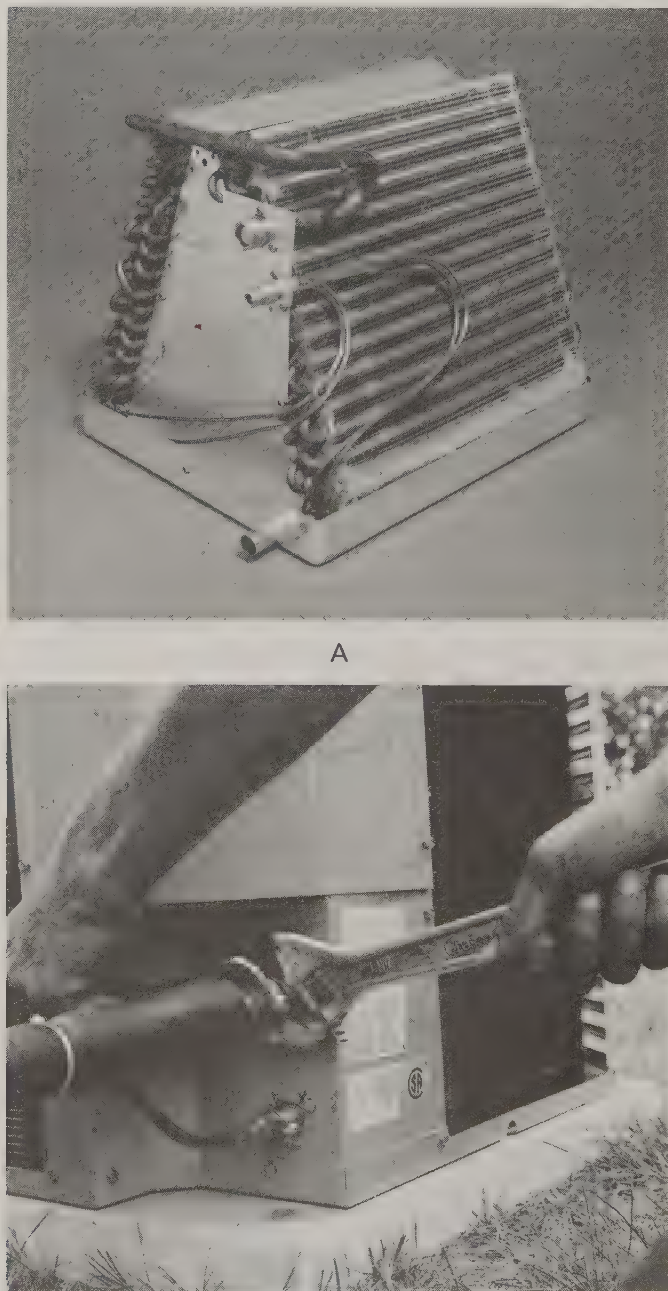


Fig. 25-27. A typical gas heating system shown in both pictorial and schematic forms.

ADD-ON AIR CONDITIONING

Air conditioning is easily added to a gas forced convection heating system. The evaporator is installed inside the furnace plenum and the condensing unit is located outdoors. The suction and liquid lines connect the evaporator to the condensing unit. The furnace blower is used to circulate air during either heating or cooling cycles. Refer to Fig. 25-28.



A

B

Fig. 25-28. Add-on air conditioning. A–The evaporator, often referred to as an "A-coil" because of its shape, is installed in the furnace plenum. B–The condensing unit is installed outside the building and connected to the evaporator by means of suction and liquid lines. (Aeroquip)

HEATING-COOLING THERMOSTAT

When heating and cooling systems are combined for year-round comfort, it is impractical to use a separate thermostat for each system. The different switching requirements are easily combined in a single thermostat and sub-base.

An additional pair of electrodes is installed in the opposite end of the glass tube, as shown in Fig. 25-29. One set of electrodes is used for the heating cycle and the other set of electrodes is used for the cooling cycle. The middle electrode is common (power supply) to both ends. When the bulb is tilted in either direction, the mercury closes the appropriate set of electrodes.

The thermostat is designed to prevent unwanted switching back and forth from heating to cooling. This involves a three-position *manual* switch on the thermostat, labeled COOL-OFF-HEAT. This switch prevents the thermostat from energizing both systems at the same time, or from automatically switching back and forth between them. See Fig. 25-30.

When the manual switch is in the OFF position, both heating and cooling systems are turned off (unable to operate). When switched to the HEAT mode, only the heating system is able to operate. The cooling mode is disconnected. When the manual switch is in the COOL mode, only the cooling system is operational. The heating mode is disconnected.

COOLING CYCLE

When the manual switch on the thermostat is switched to COOL, and the mercury closes the cooling contacts, 24V is supplied to terminal Y on the thermostat. A yellow wire connects this terminal with the coil on the contactor in the outdoor condensing unit. A white wire connects the other side of the coil to the neutral side of the 24V transformer. See Fig. 25-31. When the contactor coil is energized, the outdoor condensing unit is turned on.

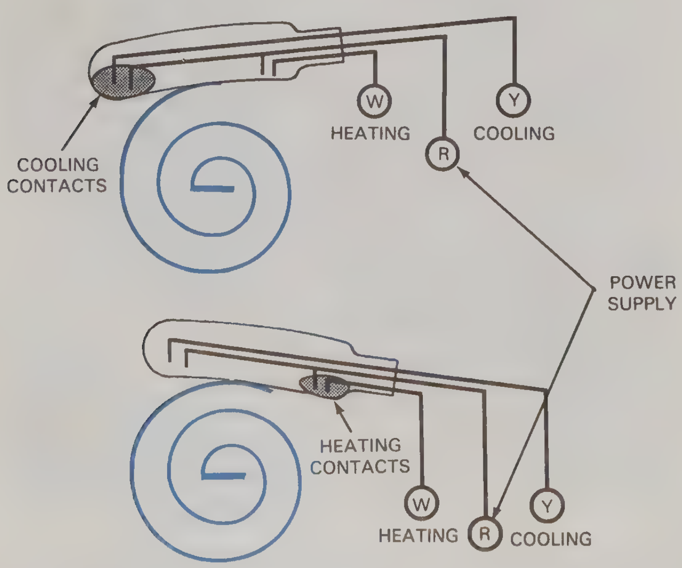
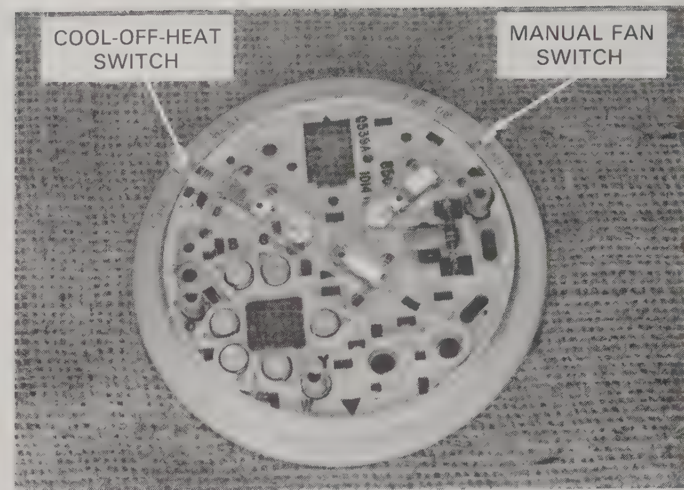


Fig. 25-29. A combination heating and cooling thermostat has two sets of electrodes at opposite ends of the glass tube. This helps avoid the possibility of operating the two systems at the same time.



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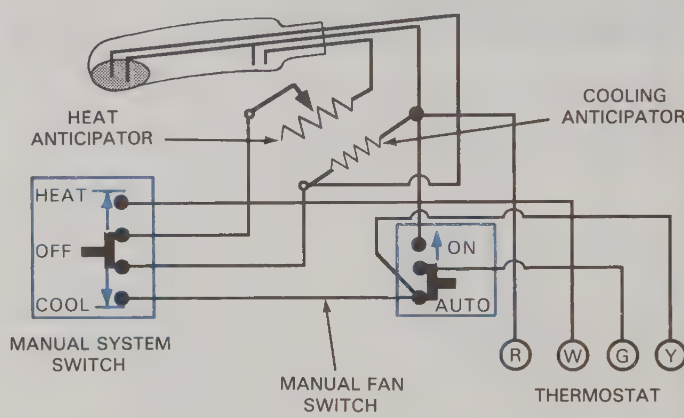


B

Fig. 25-30. Manual switching of modes. A–The COOL-OFF-HEAT manual switch is on the sub-base of the thermostat. The fan switch is also in the sub-base. B–Schematic showing connections for the manual mode switch.

Cooling anticipator

The thermostat's cooling anticipator does the same job as the heating anticipator, only in reverse. The cooling anticipator must compensate for the delay between the call for cooling and the time when the system begins delivering cool air. This anticipator is a small fixed resistor wired in parallel with the cooling mercury switch. When the mercury switch is closed during a call for cooling, the anticipator is in parallel and thus is bypassed. (Electricity always takes the path of least resistance.) See Fig. 25-32.

When the cooling demand is satisfied, the mercury switch opens. This places the cooling anticipator in *series* with the compressor contactor coil. Due to high resistance, a very small current flows through both the

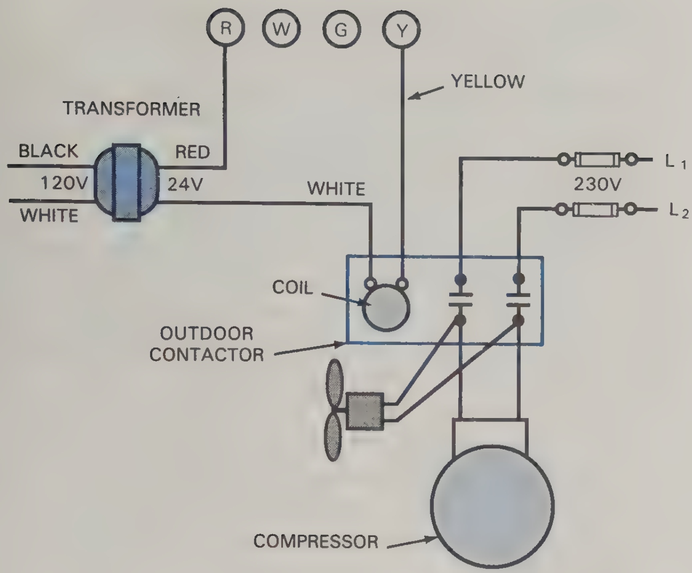


Fig. 25-31. When the cooling cycle is active, the circuit is completed from terminal Y of the thermostat to the contactor on the outdoor condensing unit.

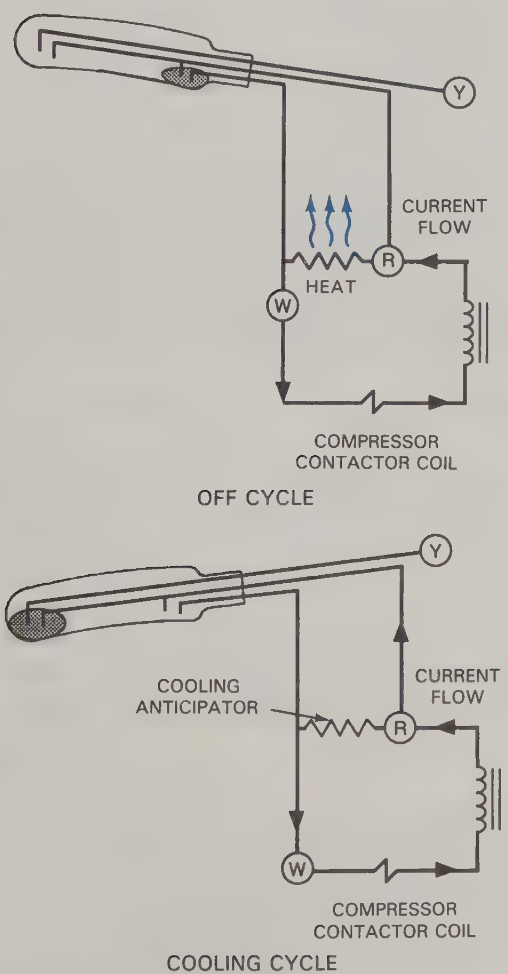


Fig. 25-32. During the cooling cycle, the cooling anticipator is bypassed. Once the mercury switch opens, the anticipator heats up from resistance and advances the bimetallic element to be slightly ahead of actual room temperature. This allows cooling to start just before the actual setpoint is reached.

anticipator and the compressor contactor coil. The amperage is not sufficient to energize the contactor coil, but does cause the resistor to heat up. This resistor heat makes the bimetallic coil tilt just slightly in advance of the room temperature. Thus, the cooling equipment has the opportunity to get started and begin delivering cool air just before the room temperature reaches the thermostat setting.

BLOWER MOTOR

The combination fan/limit switch turns on the blower motor when the furnace is hot. Provisions must be made to energize the blower motor during the *cooling* cycle, as well. A ***blower relay*** is used to accomplish this purpose. The blower relay has a 24V coil and one set of normally open contacts. When the relay coil is energized by the thermostat, the relay switch closes and completes a 120V circuit to the blower motor. See Fig. 25-33.

Another manual switch on the thermostat (the *fan switch*) controls power supply to the blower relay coil. This manual switch is labeled ON and AUTO (for "automatic"). When the thermostat calls for cooling, and the fan switch is in the AUTO position, another 24V circuit is completed to terminal G inside the thermostat. See Fig. 25-34.

Terminal G is used to control the 24V power supply to the blower relay coil. A green wire connects terminal G on the thermostat to the blower relay coil. The other side of the relay coil is connected to the neutral side of the transformer.

When the manual fan switch is in the ON position, terminal G receives a continuous 24V power supply. This keeps the blower relay coil energized, so the blower motor runs continuously. This switch permits the homeowner to control blower operation independently of the

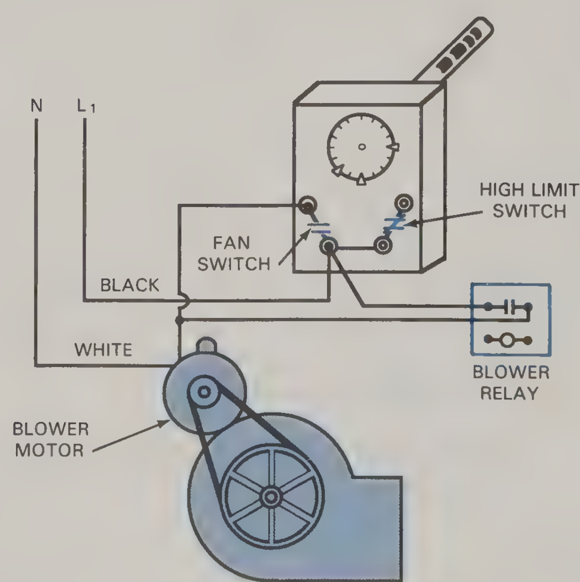


Fig. 25-33. The blower relay controls the blower during the cooling cycle.

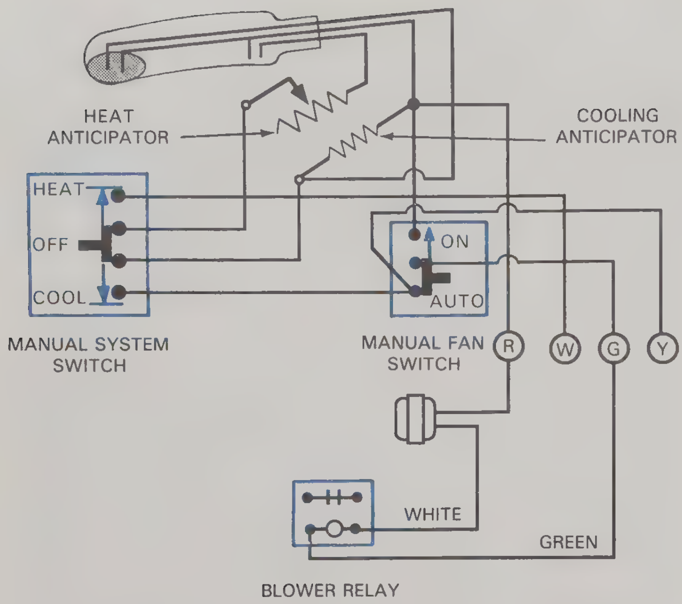


Fig. 25-34. The fan switch on the thermostat allows the selection of continuous fan operation or operation only during the cooling cycle.

COOL-OFF-HEAT switch. Sometimes air circulation only, without cooling, is adequate to satisfy the homeowner's needs.

A two-speed blower motor may be used to provide better air circulation. Low speed is used for the heating cycle because the temperature difference (*td*) through the furnace is 55°F (125 - 70 = 55). High speed is used for the cooling cycle because the td across the evaporator is 16°F to 20°F. Electrical connections for the two-speed blower motor are accomplished by connecting its low speed (heating) terminal to the fan switch and its high speed (cooling) terminal to the blower relay switch. See Fig. 25-35.

Fig. 25-36 is a schematic and pictorial of a typical gas fired, forced air furnace with air conditioning and two speed blower motor.

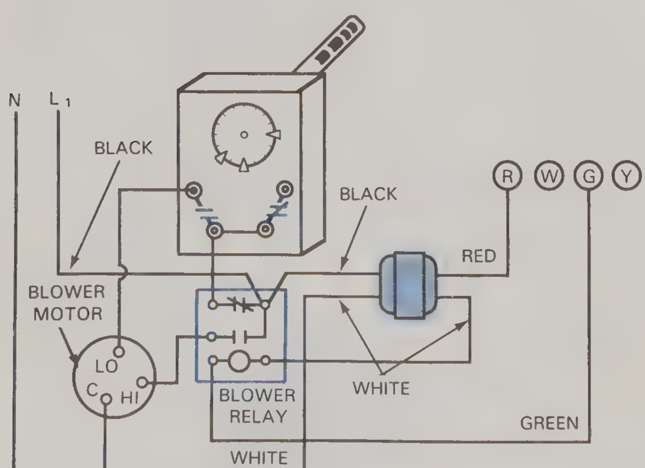


Fig. 25-35. The low speed of a two-speed fan is energized during the heating cycle; high speed during the cooling cycle.

TROUBLESHOOTING GAS FURNACES

Systematic troubleshooting requires skills that must be cultivated and developed. A service call tests the technician's knowledge, mechanical skills, and ability to observe and interpret information. Good troubleshooting requires the use of information to make a conclusion. Hasty decisions, or wrong information results in wrong conclusions. Troubleshooting involves using step-by-step procedures and a *process of elimination* to pinpoint the problem. There are five important steps involved in systematic troubleshooting:

1. Know what the equipment *should do.*
2. Know what the equipment is *doing.*
3. Know what the equipment is *not* doing.
4. Eliminate areas that *are* functioning properly.
5. Concentrate on areas that are *not* functioning properly..

The customer's complaint usually helps narrow the problem to a specific area. These complaints fall into one of six possible headings:

- No heat.
- Not enough heat.
- Too much heat.
- Noise.
- Odor.
- Excessive operating cost.

A question or two to the homeowner, plus a few observations of the equipment, should aid in the process of elimination. By listening, observing, and testing, the technician discovers clues that point to the exact problem. Some of the most likely causes are listed under each problem area.

NO HEAT

Burner does not start.

- Wrong thermostat settings.
- Defective thermostat.
- No power supply to furnace (check fuses, circuit breakers).
- Gas valve turned off.
- Defective high limit control.
- Defective transformer (check fuse, if any).
- Defective gas valve.

Pilot flame is out.

- Main gas valve turned off.
- Plugged or restricted pilot orifice.
- Pilot blows out due to draft through furnace.
- Pilot blows out due to high gas pressure.
- Pilot blows out due to delayed ignition.

Pilot flame okay.

- Thermocouple loose at valve.
- Thermocouple out of alignment at pilot.
- Defective thermocouple.

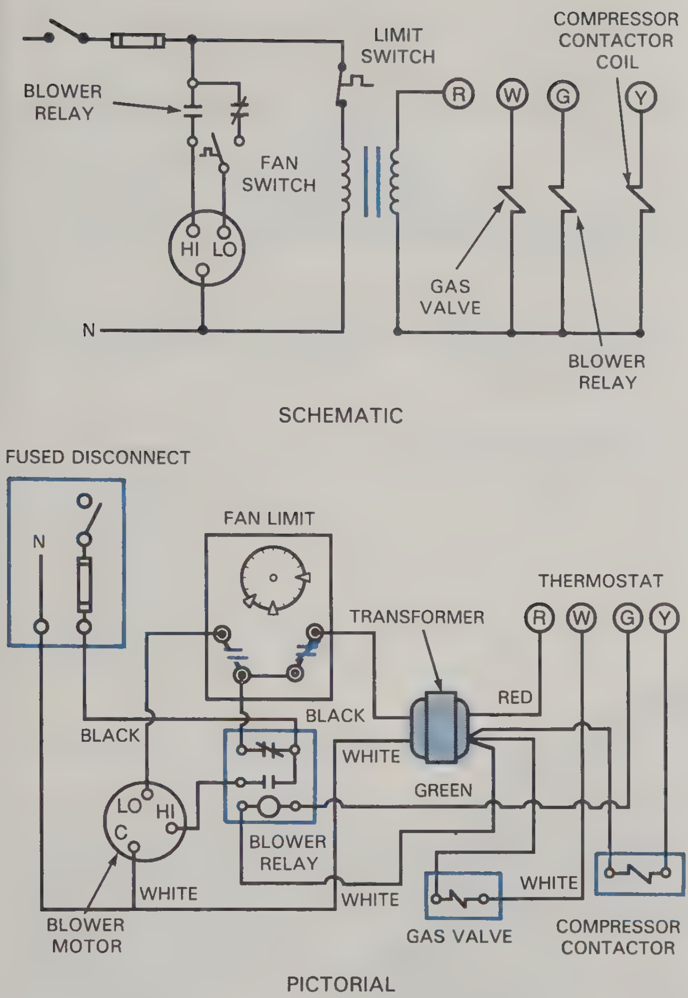


Fig. 25-36. A typical gas heating system with air conditioning added is shown in both pictorial and schematic forms.

NOT ENOUGH HEAT

Burner short cycles.

- Unit cycling on high limit control.
- Defective blower motor.
- Dirty filter.
- Loose or broken V-belt.
- Wrong rotation of blower motor.
- Restriction in return air system.
- Low voltage at motor (causes high amps).

TOO MUCH HEAT

Burner runs too long.

- Wrong thermostat settings.
- Heat anticipator set too high.
- Thermostat not level.
- Thermostat on cold wall or in draft.
- Defective gas valve (stuck open).

NOISE

- Delayed ignition causing flashback.
- Flashback after shutdown (excess primary air).
- Loose blower bearings.
- Blower bearing dry and squeaking.
- Blower wheel off-center.
- Loose V-belt.
- Loose running gear and mounts.
- Filter caught in running gear.
- Loose cabinet panels.

ODOR

- Leak in gas line or pilot line.
- Loose or cracked heat exchanger.
- Leak in flue pipe.
- Downdraft causing diverter spillage.
- Negative pressure in furnace area.
- Dirty air filters
- Stagnant water or sludge in humidifier.

EXCESSIVE OPERATING COST

- Dirty air filter.
- Poor combustion.
- Insufficient home insulation.
- Excessive air leakage (fireplace, vents, etc.)
- Excessive gas manifold pressure.
- Oversize burner orifice.
- Excessive flue draft.
- Wrong fan control settings.

SUMMARY

This chapter described the principles and operation of a gas fueled, forced convection furnace, and how it is controlled electrically. The function of each component and what purpose it served in the system was explained. Electrical connections for each component were discussed in a step-by-step manner. This concluded with both schematic and pictorial wiring diagrams for the heating system.

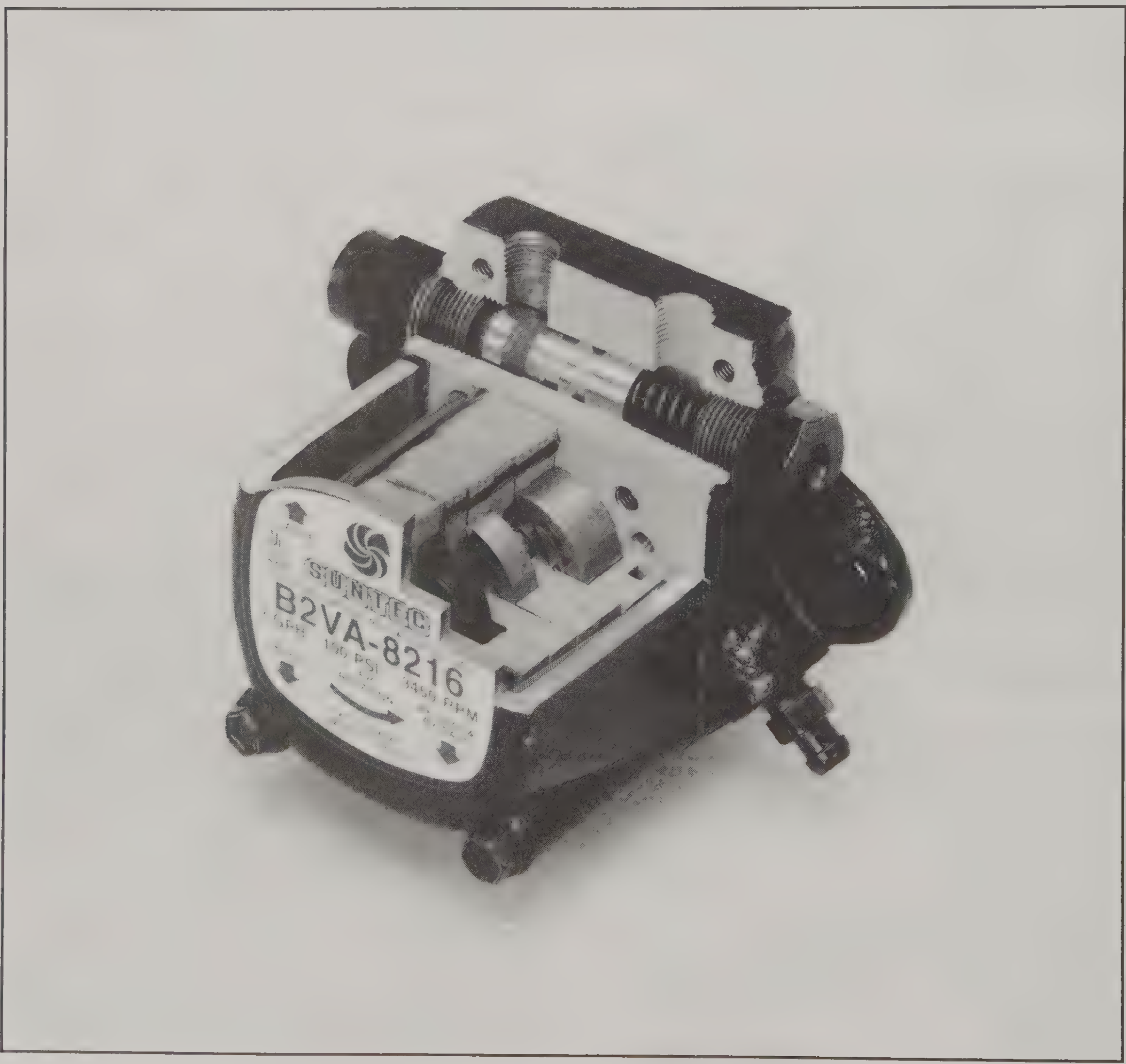
The procedure for adding air conditioning to the gas furnace also was explained, along with the operation and function of the thermostat and blower relay. Each component was explained as it was introduced and electrical connections were presented in a step-by-step manner. The electrical circuits were explained and illustrated by pictorial and schematic diagrams. Troubleshooting procedures were included to assist in understanding system operation.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What components of a heating and cooling system are used to carry treated air to and from the living space?
2. Heated or cooled air being delivered to the living space is called __________.

3. The metal box installed on the furnace outlet is the __________.
4. True or false? Registers or diffusers are used for return air.
5. Why do dirty filters reduce system capacity?
6. The gas valve controls flow to the __________.
7. What is the purpose of the thermocouple?
8. Does the fan switch control power supply to the blower during the heating or cooling cycle?
9. The limit switch opens when furnace temperature reaches about __________°F.
10. The R (red) terminal on the thermostat is connected to __________.
11. The W (white) terminal on the thermostat is connected to __________:
12. The __________ terminal on the thermostat is connected to the compressor contactor coil.
13. The G (green) terminal on the thermostat is connected to __________.
14. Which anticipator is adjustable?
15. What device turns on the blower motor during the cooling cycle?



Cutaway view of a two-stage pump used to pump oil into a furnace that is located higher than the fuel storage tank. (Suntec)

Chapter 26

OIL HEAT WITH AIR CONDITIONING

After studying this chapter, you will be able to:
- *Describe how fuel oil and air are mixed in the combustion chamber for proper combustion.*
- *Explain how the mixture of oil and air is ignited.*
- *State dimensions to be used for proper electrode placement.*
- *Define the purpose of primary air adjustments.*
- *Explain why draft control is used and how it works.*
- *Describe purpose and location of flame safeguards.*
- *Describe the electrical connections needed for heating and air conditioning circuits.*
- *Describe operation and purpose of safety controls.*

NEW WORDS

atomizing
bleed port
burner fan
cad cell
draft control
electrodes
fan relay
flame safeguard
flexible coupling
fuel oil
gap
gun-type burner assembly
ignition transformer
isolation relay
orifice
pressure tap plug
primary control
single-stage oil pump
spray angle
stack control
transient light
vaporized
viscosity

OIL-FUELED FURNACES

Oil-fueled and gas-fueled forced convection ("forced air") furnaces are similar in appearance and air circulation, but major differences exist in the combustion process and electrical circuits.

Inside an oil furnace, Fig. 26-1, fuel oil is vaporized and mixed with air in a precise ratio to obtain a combustible mixture. This oil/air mixture is ignited by an arc (spark) between two electrodes.

A high-voltage transformer is used to supply 10,000 volts to the electrodes, producing the hot spark necessary for igniting the oil/air mixture. A flame sensor is used to determine if the mixture ignites. If ignition does not occur, the flame sensor shuts the system off. This prevents filling the furnace with oil and producing a very dangerous situation.

The oil-fueled forced convection furnace is controlled by a standard 24V thermostat. The electrical circuits involved include 120V (supply voltage), 24V (control), and 10,000V (ignition). Later sections of this chapter will explain how these circuits are related to provide automatic control and safety.

FUEL OIL

Fuel oil contains more carbon than some other hydrocarbon fuels, such as natural gas and LP gas. Several grades (or weights) are available, ranging from grade No. 1 to grade No. 6. Grade No. 2 is the most popular fuel oil, and produces about 140,000 Btu/gal. It is used in gun-type (atomizing) burners. For proper combustion, the liquid oil must be changed to a gas (vaporized) and mixed with air.

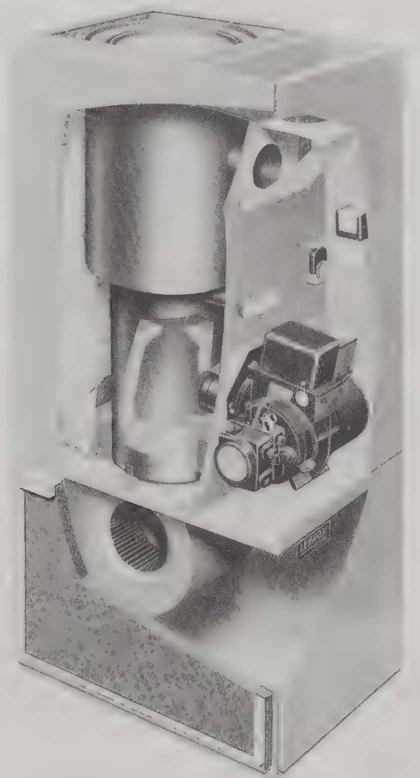


Fig. 26-1. Cutaway view of a typical oil-fueled forced convection furnace. (Lennox Industries, Inc.)

GUN-TYPE BURNER ASSEMBLY

The ***gun-type burner assembly*** is designed to produce the conditions needed to produce a steady hot flame inside the furnace. The main parts of the burner assembly are the motor, centrifugal fan (blower), oil pump, nozzle, air tube (gun barrel), ignition transformer, electrodes, and flame sensor. See Fig. 26-2.

MOTOR

A 12OV, split-phase, 1/6 hp motor is normally used to drive the oil pump and centrifugal fan. The centrifugal fan is anchored to the motor shaft and a rubber ***flexible coupling*** is used to extend (lengthen) the motor shaft so that it reaches the oil pump shaft. See Fig. 26-3. This provides a direct drive connection so that the fan and oil pump rotate at the same speed (revolutions per minute or rpm) as the motor. The motor speed may be either 1725 rpm or 3450 rpm. The oil pump and fan are designed to match the motor's speed.

BURNER FAN

A centrifugal-type ***burner fan*** is located inside the burner assembly and anchored to the motor shaft by a set screw. Its purpose is to supply primary air for mixing with oil. The air intake holes in the burner assembly are covered by an adjustable metal collar. This collar is used to regulate the volume of primary air supplied to the combustion chamber.

Air entering the intake holes is forced through an air tube (often referred to as a "gun barrel") into the combustion chamber. Special curved vanes are installed inside the end of the air tube. These vanes cause the air to twist in a swirling pattern when exiting the tube, which greatly improves mixing of air and oil vapor.

When vaporized, one gallon of fuel oil occupies a volume of 14 cubic feet (cu.ft.). It requires about 1500 cu.ft. of air to burn one gallon of No. 2 fuel oil. Air is required to obtain oxygen for combustion, and only about 20 percent of this air is oxygen.

For good combustion, excess air must be used. Actually, about 2000 cu.ft. of air (400 cu. ft. of oxygen) is mixed with each gallon of fuel oil. Considerable nitrogen, some oxygen, carbon dioxide, steam, and other impurities go up the flue and are vented through the chimney.

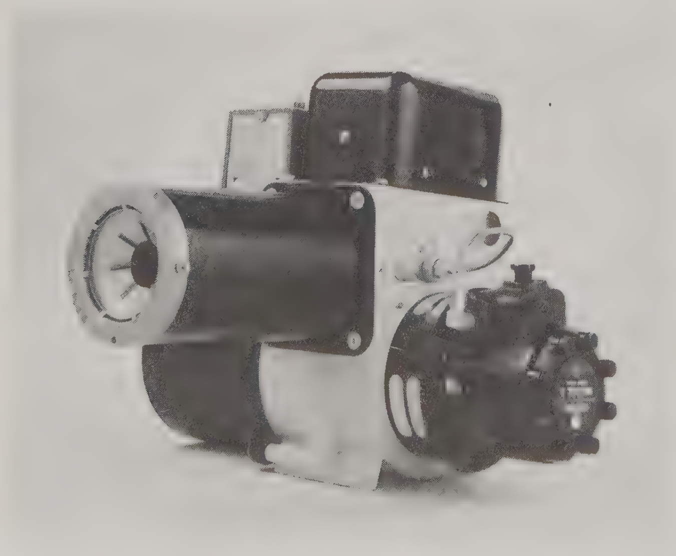


Fig. 26-2. A gun-type burner assembly for an oil-fueled furnace. (Beckett)

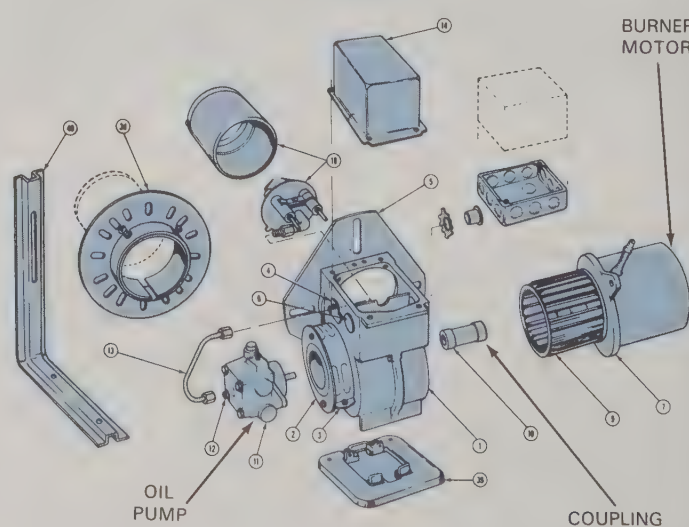


Fig. 26-3. Exploded view of a gun-type burner assembly. Note the flexible coupling that connects the oil pump and the centrifugal fan motor.

Proper airflow will produce a white/yellow flame. Too much air produces a white flame, while insufficient air results in a yellow/orange flame and the formation of soot. Generally, enough excess air is fed to the flame to produce about 10 percent carbon dioxide (CO_2) level in the flue.

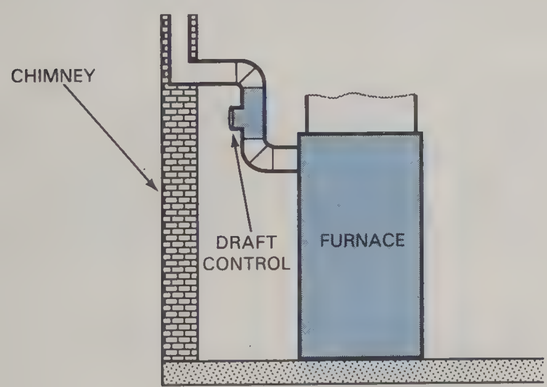
DRAFT CONTROL

A special ***draft control*** device is used on all gun type oil burners to keep the flue pressure constant. See Fig. 26-4. Without a draft control, flue pressure would vary from the effects of wind, temperature, and atmospheric pressure. Changing flue pressure would cause changes in combustion airflow, and thus changing flame quality.

The draft control maintains a constant flue pressure by regulating the amount of dilution air entering the flue. As necessary, it automatically opens to increase flue pressure and closes to reduce flue pressure. The draft control has an adjustable weight for low, medium, or high draft.

OIL STORAGE TANKS

Location of the oil storage tank determines whether one or two oil supply lines are used. When the tank is above the burner level, a one-pipe system is permitted.



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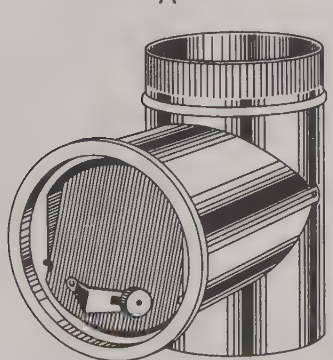


B

Fig. 26-4. Draft control device. A–The draft control is installed in the flue pipe between the furnace and the chimney. B–An adjustable weight on the draft control can be set to provide high, medium, or low draft.

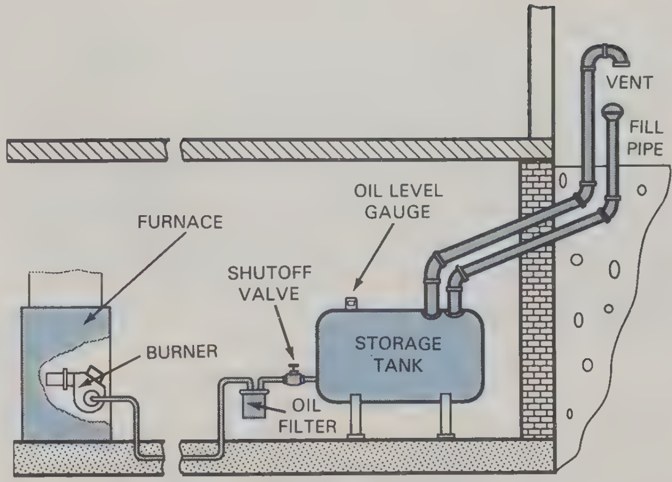


Fig. 26-5. A one-pipe supply system is used when the oil storage tank is located on the same level with, or above, the burner.

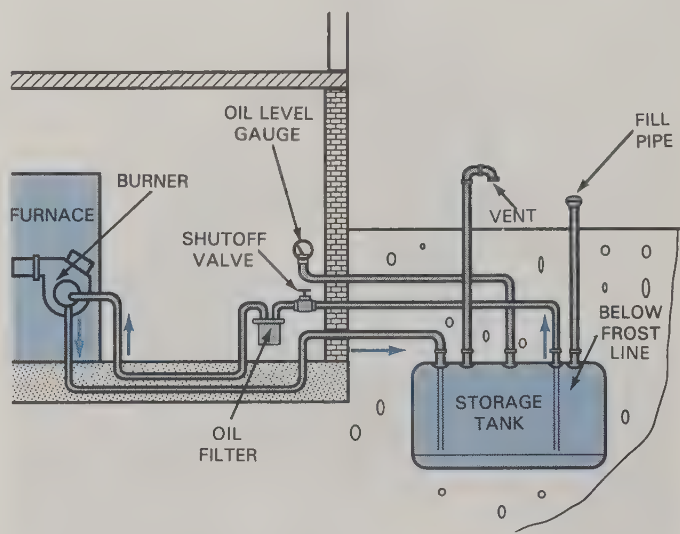


Fig. 26-6. When the oil storage tank is underground, and thus below the level of the burner, a two-pipe system is required.

Gravity draws oil downward from the tank through a shut-off valve and oil filter to the burner. See Fig. 26-5.

Cold temperatures affect the ***viscosity*** (thickness) of the oil. Cold oil may not flow properly. For this reason, the oil storage tank is installed in the basement or buried underground in cold climates. Oil storage tanks that are buried underground usually require a two-pipe system, because the tank is below the burner. See Fig. 26-6.

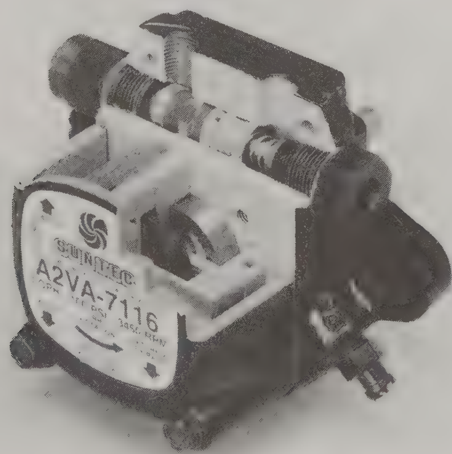
SHUTOFF VALVE AND FILTER

A manual shutoff valve is always installed as close to the tank outlet as is practical. This valve provides the necessary means of stopping oil flow when making repairs to the system. The valve is normally open and is closed manually before making repairs or changing the oil filter.

An oil filter is always installed between the shutoff valve and before the burner assembly. Typically, the filter consists of a replaceable cartridge located inside a steel housing. This replaceable cartridge is made of wool felt with a tubular wire mesh screen inserted through the core. This specially designed filter captures many fine solid impurities from the oil, preventing them from reaching the nozzle. The filter element should be replaced when clogged, or at the beginning of each heating season.

OIL PUMPS

The oil pump is located on the burner assembly and is used to increase oil pressure to 100 psig (690 kPa). Single-stage and two-stage models are used. The pumps can be of either the rotary or the gear type. See Fig. 26-7 for examples of rotary pumps.



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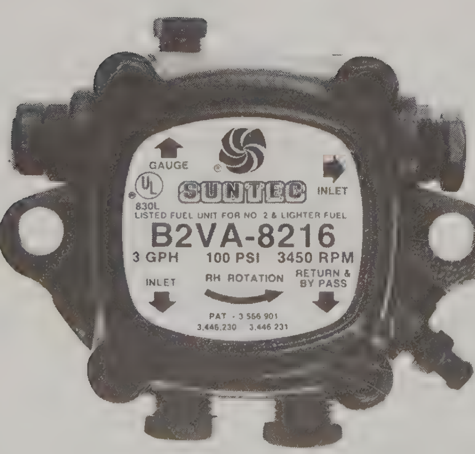

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Fig. 26-7. Fuel oil pumps used to boost oil pressure to 100 psig. A–Cutaway view of a single-stage rotary pump. B–A two-stage rotary pump. (Suntec Industries, Inc.)

SINGLE-STAGE OIL PUMP

The *single-stage oil pump* is used on one-pipe systems, where the oil storage tank is above the burner assembly. A single copper tube (3/8 in. or 1/2 in.) connects the storage tank outlet to the inlet of the single-stage oil pump. Gravity supplies the force necessary to cause oil flow from the storage tank to the oil pump. Excess oil is bypassed inside the oil pump and redirected to the oil pump inlet. If an oil pump becomes defective, it is normally replaced, not repaired.

Oil pump bleed port

Air trapped in the one-pipe system will prevent oil flow from the storage tank to the pump, causing the furnace to shut down due to lack of flame. Air can get into this pipe due to an empty storage tank, or when the system is opened. To restore proper operation, this air must be vented.

A special *bleed port* is located on the oil pump for bleeding air from the system. To bleed the system, place a 1/4 in. diameter flexible hose on the bleed port, and the free hose end in a container. Turn the bleed port nut 1/8 to 1/4 turn counterclockwise to loosen it, then start the burner. Air and some oil will be pumped into the container. Continue pumping until all air is removed and a steady stream of oil appears. To return the system to normal operation, tighten the bleed port nut and remove the hose.

Oil pump pressure tap

An oil pump has a *pressure tap plug* that is used to check pump pressure to the nozzle. With the system turned off, remove the plug and install an adapter for connecting a pressure gauge. With the system turned on, the oil pressure can be adjusted by a screw located on the pump.

TWO-STAGE OIL PUMP

A two-stage oil pump is used on a two-pipe system where the storage tank is located below the burner assembly. The first stage pulls oil from the storage tank, and the second stage provides the 100 psig pressure to the nozzle. Excess oil is channeled through a bypass inside the oil pump and is returned to the storage tank through the second pipe. Two-stage oil pumps are self-priming and do not require bleeding of air.

NOZZLE

Oil will not burn in the *liquid* state. Instead, it must be *vaporized* (turned into a gas). Liquid oil will turn into a gas more quickly if it is first converted to a spray of fine droplets. This spraying process is called *atomizing.* Liquid oil at a pressure of 100 psig is fed through a tube to a nozzle with a small *orifice* (hole). See Fig. 26-8. A steel oil supply tube is mounted down the center of the

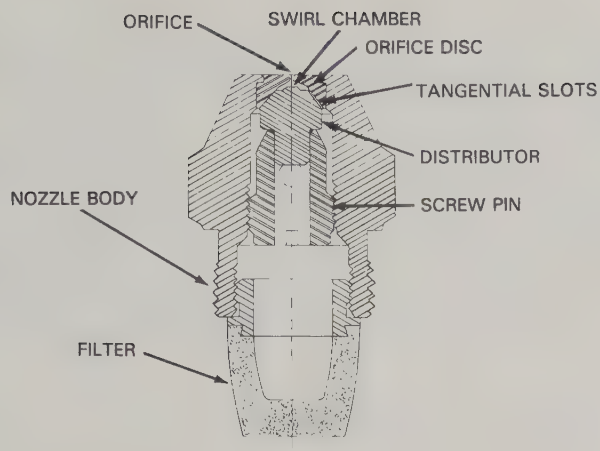


Fig. 26-8. Cross-sectional view of a nozzle used in a gun-type oil burner. (Delavan)

air tube, with the nozzle attached to the supply tube's end. This method locates the nozzle in the center of the airflow, and just inside the end of the air tube. See Fig. 26-9.

The nozzle orifice causes the oil to break up into tiny particles (droplets). These tiny droplets are sprayed into the furnace combustion chamber in a cone-shaped circular pattern. Three different spray patterns are available, Fig. 26-10. The hollow cone is most popular. A swirl chamber inside the nozzle causes a circular twisting of the oil spray. This twisting motion opposes the twisting pattern of the airflow, providing excellent mixing of oil with primary air.

Nozzles are normally equipped with a fine sintered filter at the fuel inlet end, Fig. 26-11. This filter is designed to prevent dirt from plugging the nozzle orifice. This filter should be cleaned or replaced when servicing the burner assembly.

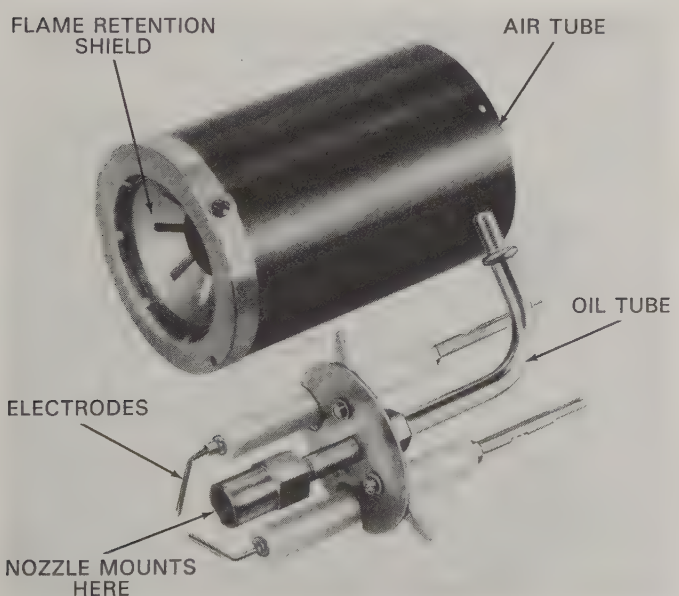


Fig. 26-9. The oil tube, nozzle, and electrodes form an assembly that is housed inside the air tube.

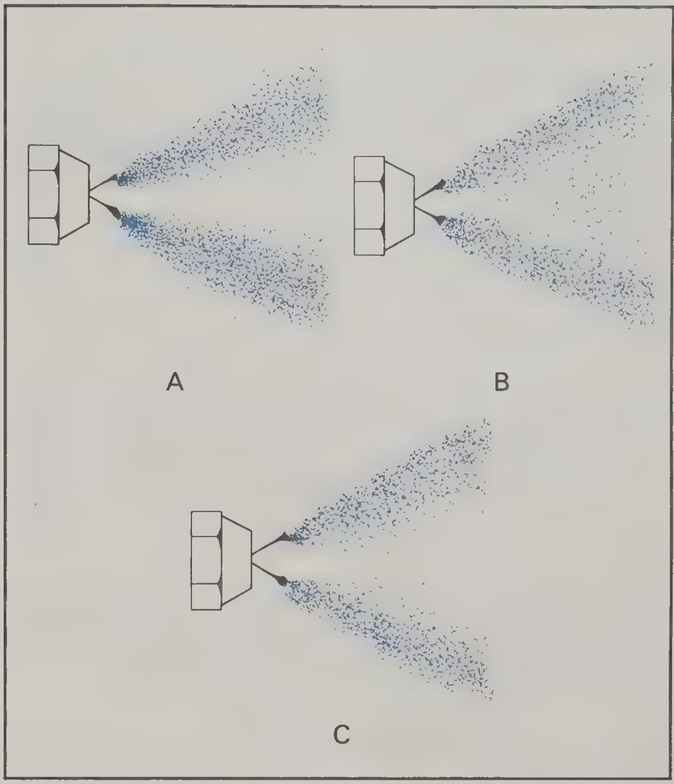


Fig. 26-10. Oil spray patterns. A–The hollow cone is the most popular pattern. B–The solid cone pattern is used for larger burners. C–The Type W nozzle provides a cone with a pattern midway between the hollow and solid patterns. (Delavan)

Fig. 26-11. A sintered metal filter at the base of the nozzle traps contaminant particles that might clog the tiny orifice. (Delavan)

NOZZLE ORIFICE

The size of the nozzle orifice is calibrated to permit a specific flow of oil at 100 psig (690 kPa). The nozzle orifice rating, in gallons per hour (gph), is stamped into the side of the nozzle body. A nozzle marked 1.0 will deliver one gallon per hour, while one rated at .75 will deliver .75 gph. The rate of oil flow must not exceed the capacity of the combustion chamber.

SPRAY ANGLE

The nozzle is designed to provide a steady, uniform spray at a specific angle. This *spray angle* must conform to the combustion chamber and burner requirements. The angle of spray is marked on the side of the nozzle body along with gph. The angle can vary from 30° to 90°.

When replacing a defective nozzle, always use an exact match in flow rate (gph) and spray angle (degrees). If the nozzle is too small, the burner may not heat the space properly. If the nozzle is too large, the burner will cycle on and off too frequently.

ELECTRODES

Two electrodes are used to produce a high voltage spark to ignite the mixture of oil vapor and air. See Fig. 26-12. The ***electrodes*** are conductors (in this case, stainless steel rods) with ceramic insulators to keep them from being becoming accidentally ("shorted") or grounded to the mounting bars. The flat brass mounting bars connect the electrodes to the high-voltage (10,000V) transformer secondary terminals.

ELECTRODE SETTINGS

Correct setting of the electrode tips is critical to achieving proper ignition. The electrode ends are positioned in front of and above the nozzle opening, with a *gap* of 1/8 in. to 3/16 in. (3mm to 5mm) between tips. High voltage from the transformer causes a continuous spark from tip to tip. This spark is required to ignite the oil/air mixture.

Where the spark occurs is very important. The spark should occur at the *outside edge* of the spray cone, not inside the spray. Residential units require the spark to occur 1/2 in. (13mm) in front of the nozzle, and the same distance *above* the nozzle opening. This prevents arcing to the nozzle. Fig. 26-13 illustrates proper placement of the electrode tips.

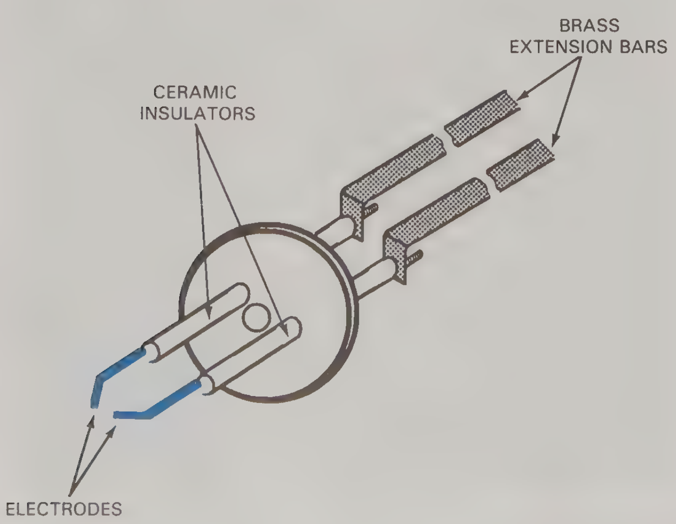


Fig. 26-12. Typical electrode assembly for an oil-fueled furnace.

IGNITION TRANSFORMER

The ***ignition transformer*** is a step-up transformer (120V to 10,000V) that is mounted on top of the burner assembly. One side is hinged for easy access to connections and components beneath the transformer. The transformer terminals must make firm contact with the electrode extension bars. See Fig. 26-14.

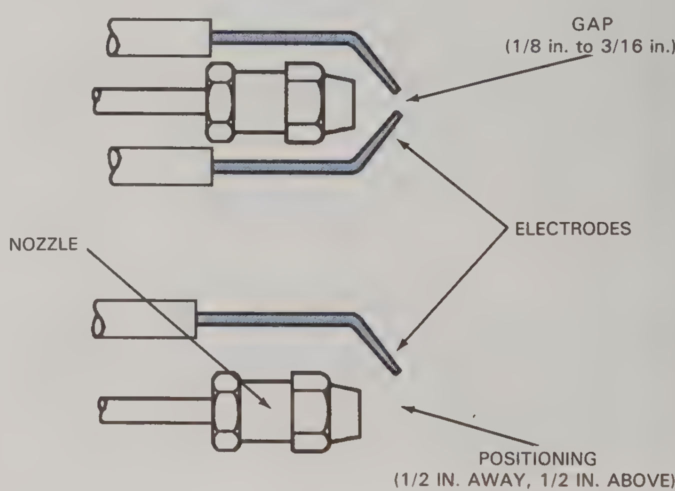


Fig. 26-13. Proper placement and gapping of electrodes.

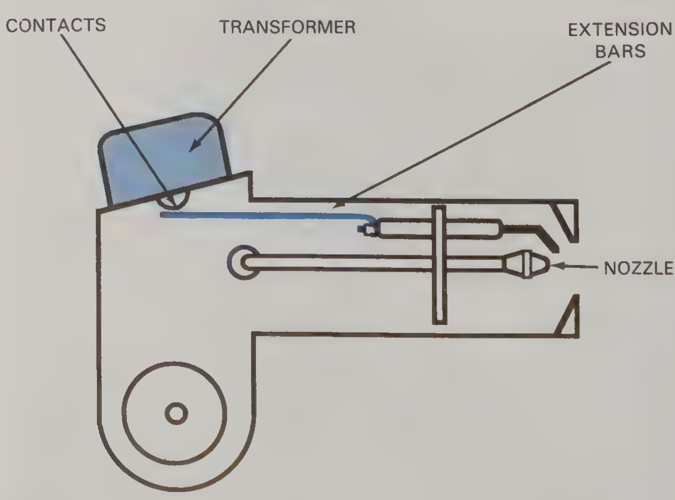


Fig. 26-14. The transformer is hinged for access to components beneath it. The transformer contacts must press firmly on the extension bars for good electrical conduction.

PRIMARY CONTROL

The *primary control* is normally located beside the burner transformer. It contains a small 24V transformer, relays, heaters, and all the switches necessary for safe operation of the burner motor and ignition transformer. See Fig. 26-15. The primary control has black, white, and orange external wires for line voltage (12OV) connections. Four screw-type electrical terminals are located on a terminal strip at the side of the control. These are low-voltage connections.

Two of the low voltage terminals (usually marked T and T or T and TA), are thermostat connections. The T terminals are used for connecting the thermostat to the primary control. The other two terminals on the primary control are marked with S or F. ("S" represents safety and "F" represents flame safeguard, which means the same thing.) These two terminals are used to connect the *cad cell,* which is explained later in this chapter.

Most oil furnaces use a combination fan-limit control (described in Chapter 25) for blower operation and high limit safety. The limit switch is connected in series with power supply to the primary control (black wire). See Fig. 26-16. The high limit is set for 200°F (93°C) to protect the furnace against overheating. When the limit switch opens, power supply to the primary control is disconnected and the furnace shuts down. The furnace blower motor is controlled by the fan switch, with a cut-in setting of 140°F (60°C) and a cut-out of 100°F(38°C).

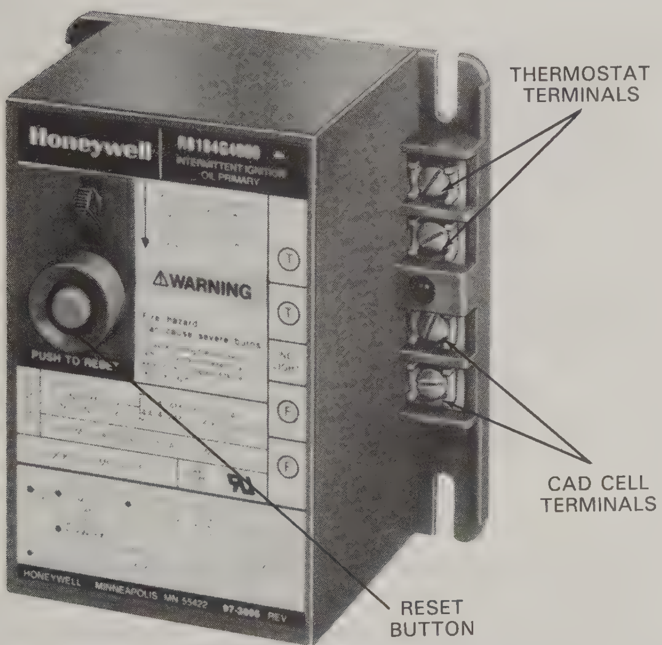


Fig. 26-15. The primary control is an electrical device that functions as a safety control. It is usually mounted next to the burner transformer. (Honeywell)

PRIMARY CONTROL CIRCUITS

The primary control contains a relay that controls the power supply to the burner motor and ignition transformer (orange wire). This relay has two sets of normally open contacts that are controlled by a coil located in the low voltage control circuit. The orange wire is connected to one of the relay contacts where line voltage travels to the ignition transformer. Fig. 26-17 illustrates these circuits.

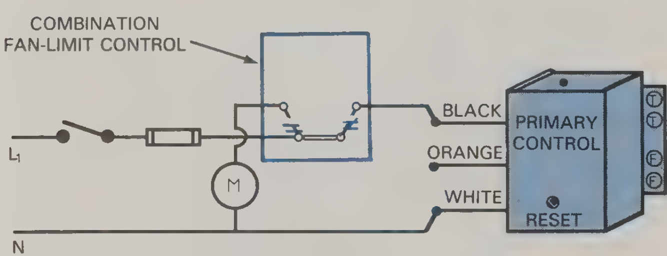


Fig. 26-16. Line voltage connections to the primary control. The combination fan-limit control is in series with the primary control.

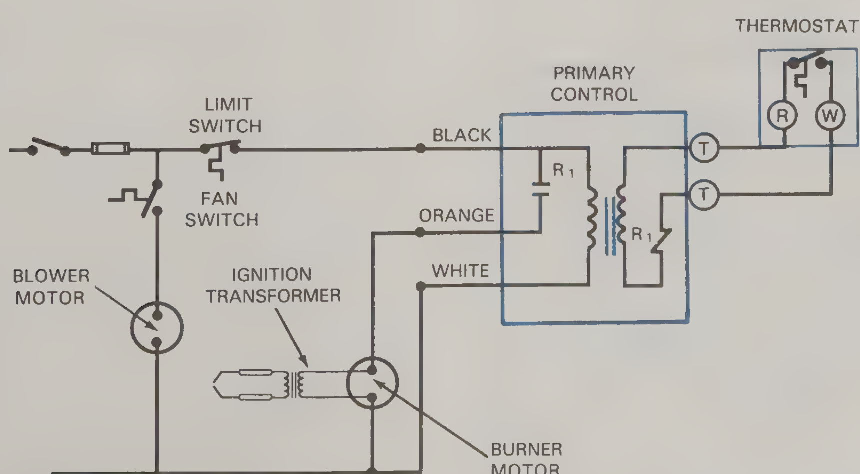


Fig. 26-17. The relay (R_1) controls power supplied to the ignition transformer and burner motor.

When the heating thermostat switch closes, a 24V circuit is completed to the relay coil. This closes the contacts in the 120V circuit, supplying line voltage to the burner motor and ignition transformer via the orange wire.

The primary control contains another relay (R_2) with two sets of contacts (one NO and one NC). In addition, a 24V heater is used to activate a bimetallic safety control switch. These additional controls and circuits provide the necessary safety features for an oil-fueled furnace. Fig. 26-18 is a typical oil primary control showing the internal circuits.

On a call for heat from the thermostat, a 24V circuit is completed to the relay coil R_1, as shown in Fig. 26-19. This circuit will energize the coil on the R_1 relay for an initial start-up. This closes the two NO R_1 contacts. One of these contacts is in the 24V circuit and the other is in the 120V circuit.

Fig. 26-20 illustrates the initial start-up circuits. At this time, the burner motor is pumping oil and air into the combustion chamber and the electrodes are sparking to ignite the mixture. If a flame does not occur (furnace does not light) within 45 seconds, the heater will

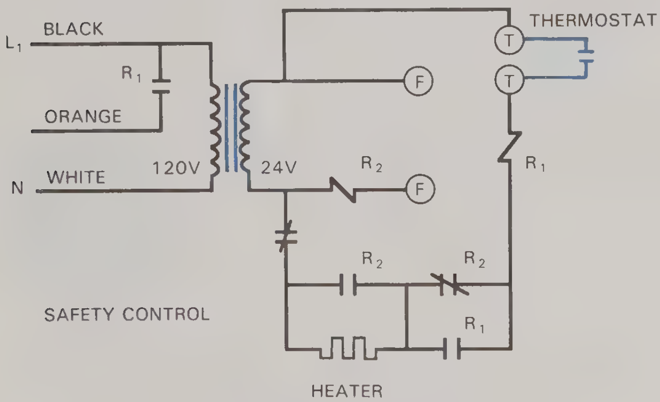


Fig. 26-18. Circuits in a typical primary control. Note the two relays.

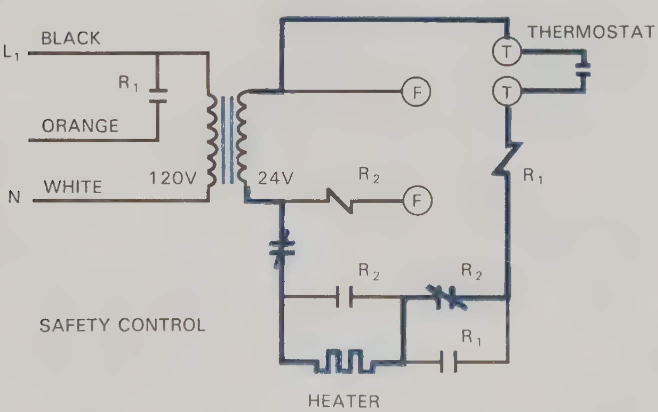


Fig. 26-19. Internal circuits of the primary control, with color showing those energized by a call for heat from the thermostat.

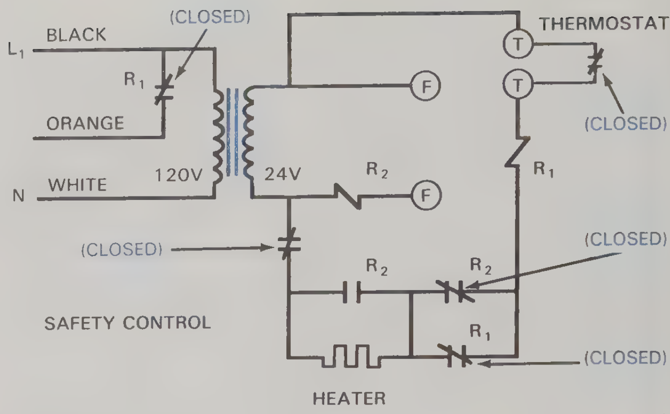


Fig. 26-20. Status of the primary control circuits and switches at start-up.

cause the bimetallic safety control contacts to open. This deenergizes the entire circuit, locking out on safety. To restart, the reset button on the primary control must be pressed.

CAUTION: Do not reset the primary control too often. Unburned oil will accumulate inside the furnace after each reset. When ignited, this pool of oil will burn intensely. *Do not attempt to put this fire out.* Instead, shut the burner off (disconnect one of the thermostat wires from the primary control "T" terminals). Close the primary air intake. Let the fire burn with reduced air intake. Permit the furnace blower motor to operate and remove heat. If necessary, call the fire department.

FLAME SAFEGUARD

The oil-fueled furnace must have protection against malfunction. The most serious problem would be loss of flame. To prevent the furnace from filling with oil, it must be turned off when loss of flame occurs. The most common method of providing a ***flame safeguard*** is by using a ***cadmium sulfide flame detector,*** commonly called a ***cad cell.*** See Fig. 26-21.

The cad cell is very sensitive to light, especially in the yellow wavelengths, and will conduct electricity when exposed to light. In darkness, cadmium sulfide becomes an insulator, preventing electron flow. This unique ability of the cad cell is used to detect the flame in an oil furnace.

In darkness, the resistance of a cad cell is about 100,000Ω. This is great enough to prevent current flow. When exposed to light, the resistance immediately drops to less than 1600Ω. This permits enough current flow to energize a relay coil. A well-balanced combustion flame causes the cad cell resistance to drop into the 300-1000Ω range.

Location of the cad cell is important. It is normally located at the rear of the air tube and directly under the ignition transformer. See Fig. 26-22. Two yellow wires from the cad cell are connected to the two "F" terminals on the primary control. When the burner ignites, the

cad cell must be able to "see" the flame. Locating the cell inside the burner assembly protects the cad cell from other sources of light (called ***transient light***). Ambient temperature of the cad cell cannot exceed 140°F (60°C). Care must be taken to keep the cad cell clean.

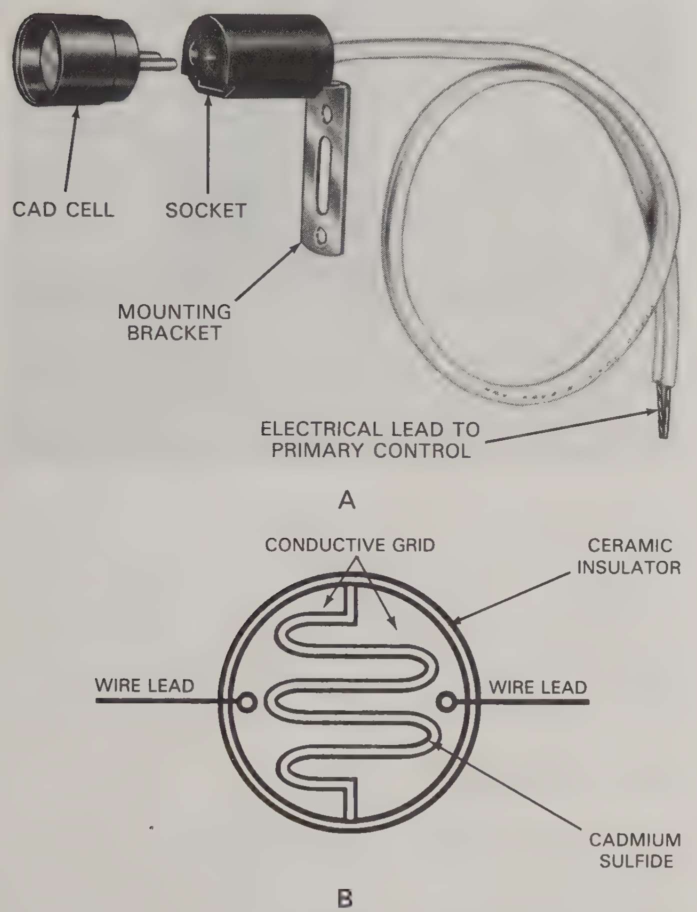


Fig. 26-21. Cadmium sulfide flame detector. A–Cad cell assembly. (Honeywell) B–Face of a cad cell.

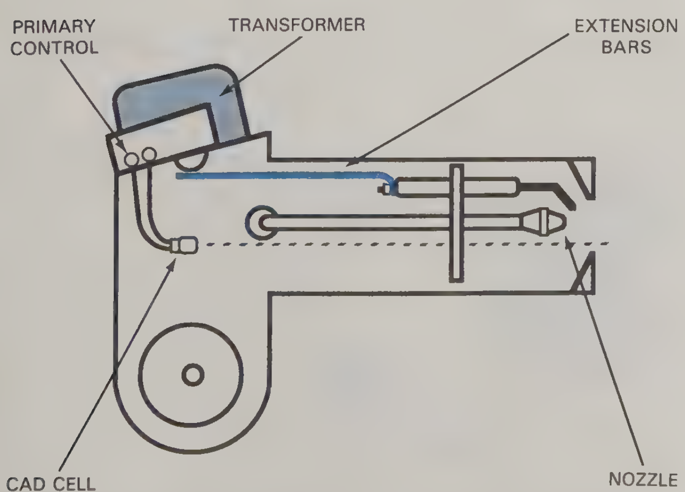


Fig. 26-22. The cad cell must be positioned where it can "see" the flame and permit current to flow. Placement inside the air tube also protects it from damage.

CAD CELL SAFETY CIRCUIT

After start-up and ignition is accomplished, the cad cell responds to the flame and completes a circuit to the relay coil. This energizes the coil and causes the two R_2 contacts to reverse position. (The NO contacts close and the NC contacts open.) See Fig. 26-23. This switching of the R_2 contacts removes the heater from the circuit. Electricity always takes the path of *least resistance,* so current will bypass the heater by going through the closed contact at R_2.

If the cad cell cannot detect a flame, the R_2 coil cannot be energized. Therefore, current continues to pass through the heater. After 45 seconds, the heat will cause the safety contacts to open. This locks out the system. It cannot be restarted until the reset button on the primary control pressed.

If transient light *is* falling on the cad cell, the R_2 coil will remain energized. The system cannot start because the R_1 coil cannot be energized.

STACK CONTROL

Older oil furnaces may use a ***stack control*** instead of a primary control. The stack control performs the same function as the primary control, but uses a bimetallic

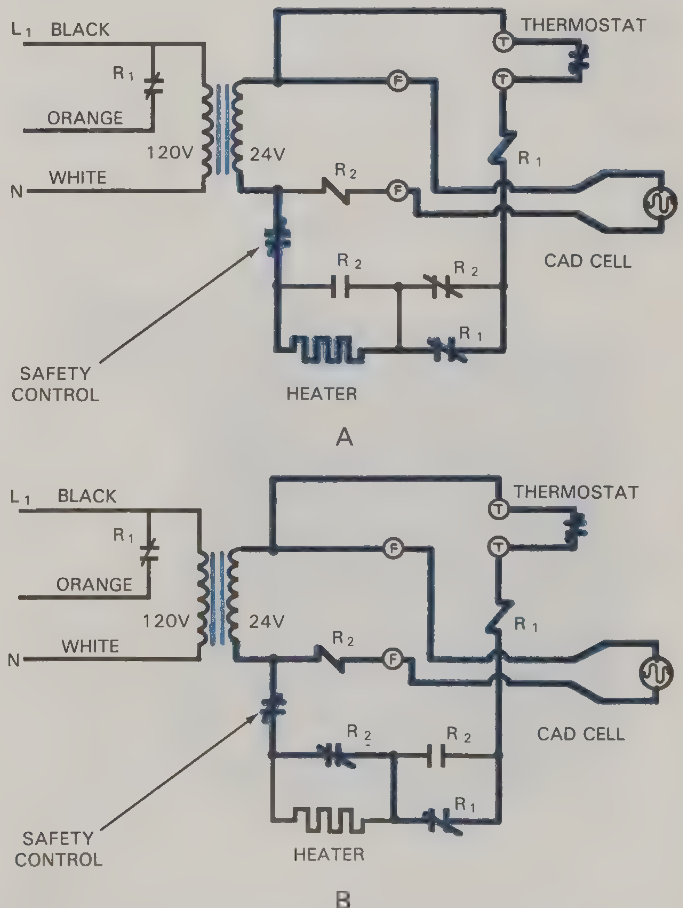


Fig. 26-23. Circuits at start-up. A–Before a flame is detected by the cad cell. B–After a flame is detected by the cad cell.

sensing element instead of a cad cell. See Fig. 26-24. The bimetal sensing element is located inside a shaft connected to the rear of the control. This shaft containing the sensing element must be inserted in the stack (flue) at the furnace outlet, before the damper control, as shown in Fig. 26-25.

Upon start-up, a heater is energized inside the stack control. This heater controls a bimetallic safety switch, just like the primary control. Flame in the combustion chamber creates hot flue gases, which the stack control senses. Heat from the flue gases causes the sensing element to expand, opening a switch to cut off power to the safety switch heater. The furnace will then continue to operate until the thermostat is satisfied.

If ignition does not occur, there are no hot flue gases. In about 60 seconds, the heater will cause the safety switch to open. This disconnects power to the burner and shuts off the furnace. Start-up cannot take place until the manual reset button on the stack control is pressed.

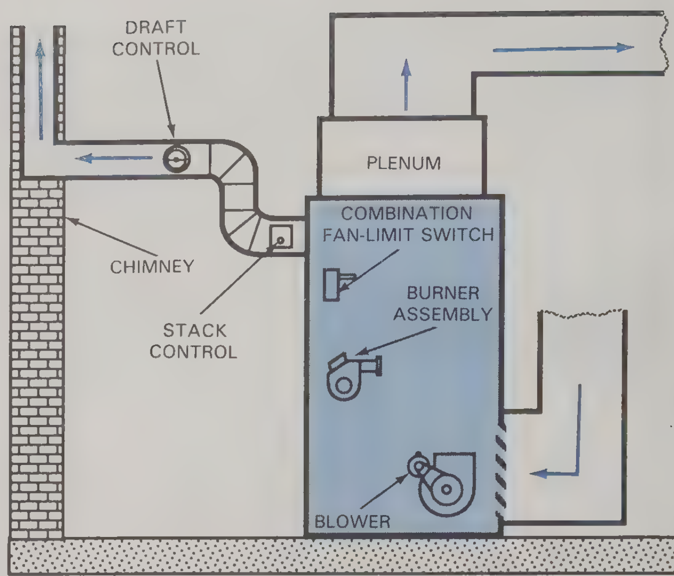


Fig. 26-25. The stack control sensing element must be located in the flue, between the furnace and the draft control. It senses flue temperature to verify the presence of a flame in the combustion chamber.

AIR CONDITIONING WITH OIL HEAT

Some additional electrical components are required to add air conditioning to an oil furnace. These components are a standard heating-cooling thermostat, a 40VA transformer, an isolation relay, and a blower relay.

COOLING TRANSFORMER

The small transformer inside the primary control cannot be used for the cooling cycle. Another transformer is required to supply 24V for the control circuits. The heating and cooling circuits *must* be separated to avoid conflict between the two transformers. The 40VA cooling transformer is used to supply 24V to a standard heating-cooling thermostat at the R terminal. The thermostat is not connected to the primary control heating terminals (T and T).

Fig. 26-24. A stack control uses a bimetallic sensing element, rather than the cad cell used by the primary control. (Honeywell)

ISOLATION RELAY

An ***isolation relay*** is used to control the heating cycle and also to separate the two control circuits. See Fig. 26-26. Upon a call for heat from the thermostat, 24V power supply travels from the thermostat's W terminal to the isolation relay coil. This energizes the isolation relay coil, causing its contacts to close.

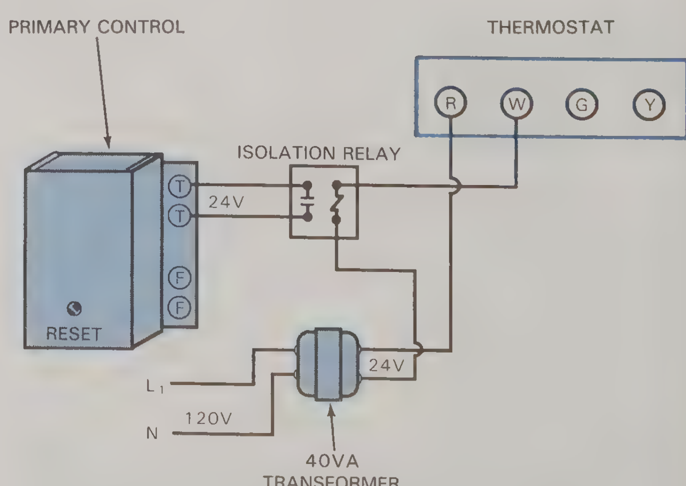


Fig. 26-26. An isolation relay separates the heating and cooling circuits and controls the heating cycle.

The primary control "T" terminals are connected to the isolation relay contacts. The primary control supplies the necessary 24V to operate the heating circuits. Thus, the isolation relay both controls the heating cycle *and* separates the two control circuits.

FAN RELAY

A ***fan relay*** is needed to operate the furnace blower motor during the cooling cycle. If the blower has a single-speed motor, only one contact (NO) is needed for the fan relay. If the blower has a two-speed motor, the fan relay has two sets of contacts (one NO, one NC). The NC contact is used for low speed (heating cycle) and the NO contact for high speed (cooling cycle). Fig. 26-27 is a schematic of a typical oil furnace with air conditioning and a two-speed blower motor.

TROUBLESHOOTING OIL FURNACES

As noted in Chapter 25, systematic troubleshooting of heating and cooling systems requires skills that must be cultivated and developed. A service call tests the technician's knowledge, mechanical skills, and ability to observe and interpret information. Good troubleshooting require the use of information to make a conclusion. Hasty decisions, or wrong information results in wrong conclusions. Troubleshooting involves using step-by-step procedures and a *process of elimination* to pinpoint the problem. There are five important steps involved in systematic troubleshooting:

1. Know what the equipment *should do*.
2. Know what the equipment is *doing*.
3. Know what the equipment is *not* doing.
4. Eliminate areas that *are* functioning properly.
5. Concentrate on areas that are *not* functioning properly.

The customer's complaint usually helps narrow the problem to a specific area. These complaints fall into one of six possible headings:

- No heat.
- Not enough heat.
- Too much heat.
- Noise.
- Odor.
- Excessive operating cost.

A question or two to the homeowner, plus a few close observations of the equipment, should aid in the process of elimination. By listening, observing, and testing, the technician should usually be able to discover clues that will point to the exact problem. Some of the most likely causes of oil furnace problems are listed under each problem area.

NO HEAT

Burner does not start after reset of primary control.

- Wrong thermostat settings.
- No power supply to furnace (blown fuse or circuit breaker).
- Loose or broken wiring connections.
- High limit switch is open.
- Defective primary control.

No flame, burner runs 45 seconds after reset and locks out.

- Oil tank out of oil.
- Clogged filter in oil line.
- Water in supply line.
- Burner motor not running (check status of the reset button).
- Clogged or damaged nozzle.
- Low oil pump pressure (check coupling).

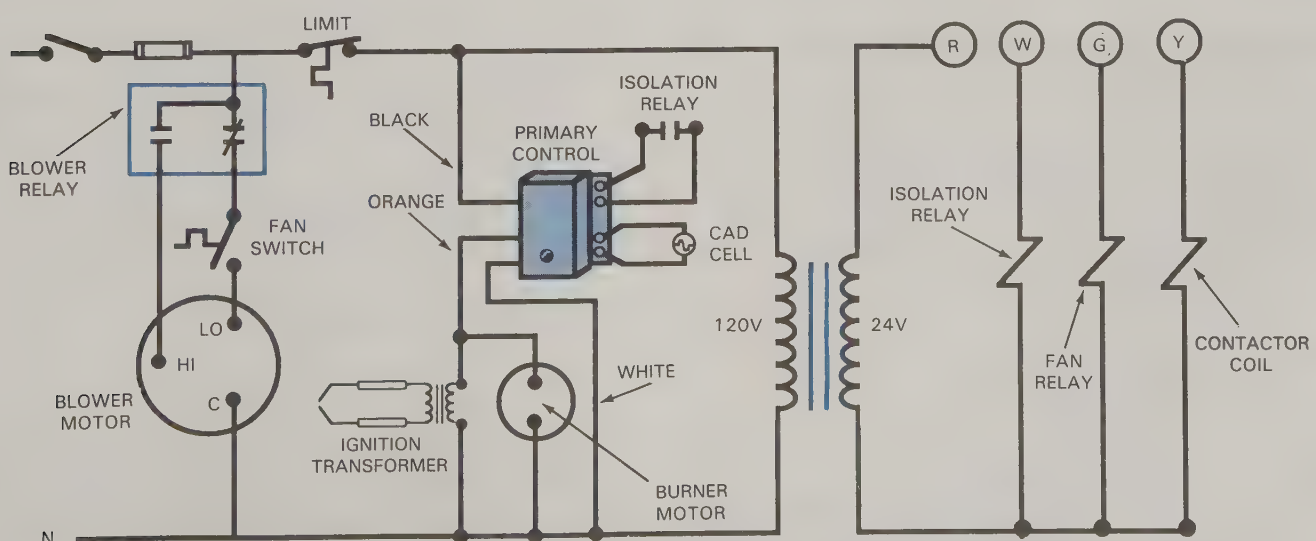


Fig. 26-27. A schematic of a typical oil furnace with air conditioning installed. A two-speed blower motor is used.

No spark at electrodes
- Wrong electrode spacing.
- Cracked electrode insulation.
- Carbon and sludge filling gap.
- Poor contact on extension bars.
- Defective ignition transformer.

Good flame, burner locks out after 45 seconds
- Dirty cad cell.
- Transient light to cad cell.
- Poor alignment of cad cell (cannot see flame).
- Defective cad cell
- Dirty sensing element on stack control.
- Defective stack control.

NOT ENOUGH HEAT

Cycles, but not on lockout.
- Wrong thermostat settings.
- Defective thermostat.
- Wrong settings on fan control.
- Defective fan control.
- Dirty air filter.
- Broken blower belt.
- Defective blower motor.
- Defective high limit switch.
- High limit switch set too low.

TOO MUCH HEAT

Burner runs too long
- Thermostat not level.
- Thermostat in cold draft.
- Thermostat located on cold wall.
- Defective thermostat.
- Defective primary control.

NOISE

Combustion noise due to delayed ignition.
- Too much combustion air.
- Excessive flue draft.
- Poor or off-center oil spray.
- Improper electrode gap or position.
- Loose electrode leads.
- Cracked or broken electrode insulators.
- Air or water in the oil system.

Noisy burner shutdown
- Air in the pump and oil system.
- Incorrect draft setting.
- Incorrect nozzle angle and type.
- Faulty nozzle resulting in poor flame.
- Poor oil pump shutoff, causing oil drip at nozzle after shutdown. (Install solenoid valve in high pressure oil line.)

Mechanical noise in burner section
- Oil pump whine due to restricted oil supply.
- Noisy oil pump (gears, bearings, etc.).
- Loose coupling.
- Burner fan loose or rubbing against housing.
- Loose burner mounting bolts.

Mechanical noise in furnace blower section
- Loose shaft bearings, allowing side-play.
- Dry blower bearings.
- Defective (worn) blower bearings.
- Blower wheel rubbing housing.
- Blower wheel out of balance, vibrating.
- Filter parts caught in blower wheel.
- Loose or damaged V-belt.
- Motor and blower pulley not aligned.
- Noisy motor bearings.
- Loose motor mounts.
- Loose furnace cover panel.

ODOR

Fuel oil
- Leak in oil lines.
- Oil tank not properly vented.
- Seepage around fill and vent connections on oil tank. (Occurs after an overfill of tank.)
- Seepage through oil pump gasket.
- Loose high pressure oil line connections.
- Leakage at oil filter.

Combustion
- Poor flue draft.
- Loose or damaged heat exchanger.
- Loose or open inspection door.
- Loose flue pipe joints.
- Delayed ignition at start-up.
- Chimney downdrafts.

EXCESSIVE OPERATING COST

- Low combustion efficiency.
- Excessive heat loss from exhaust vents, fireplaces, insulation, or other sources.
- Dirty air filter.
- Furnace temperature too high (speed up blower).
- Nozzle too large, causing short on-cycles.
- Excessive flue draft.
- Oil pressure too high or too low.
- Dirty combustion chamber.

SUMMARY

This chapter explained the differences between an oil-fueled furnace and other types of furnaces. The combustion process and ignition method were explained in detail, covering the purpose, location and operation of each component. The various components

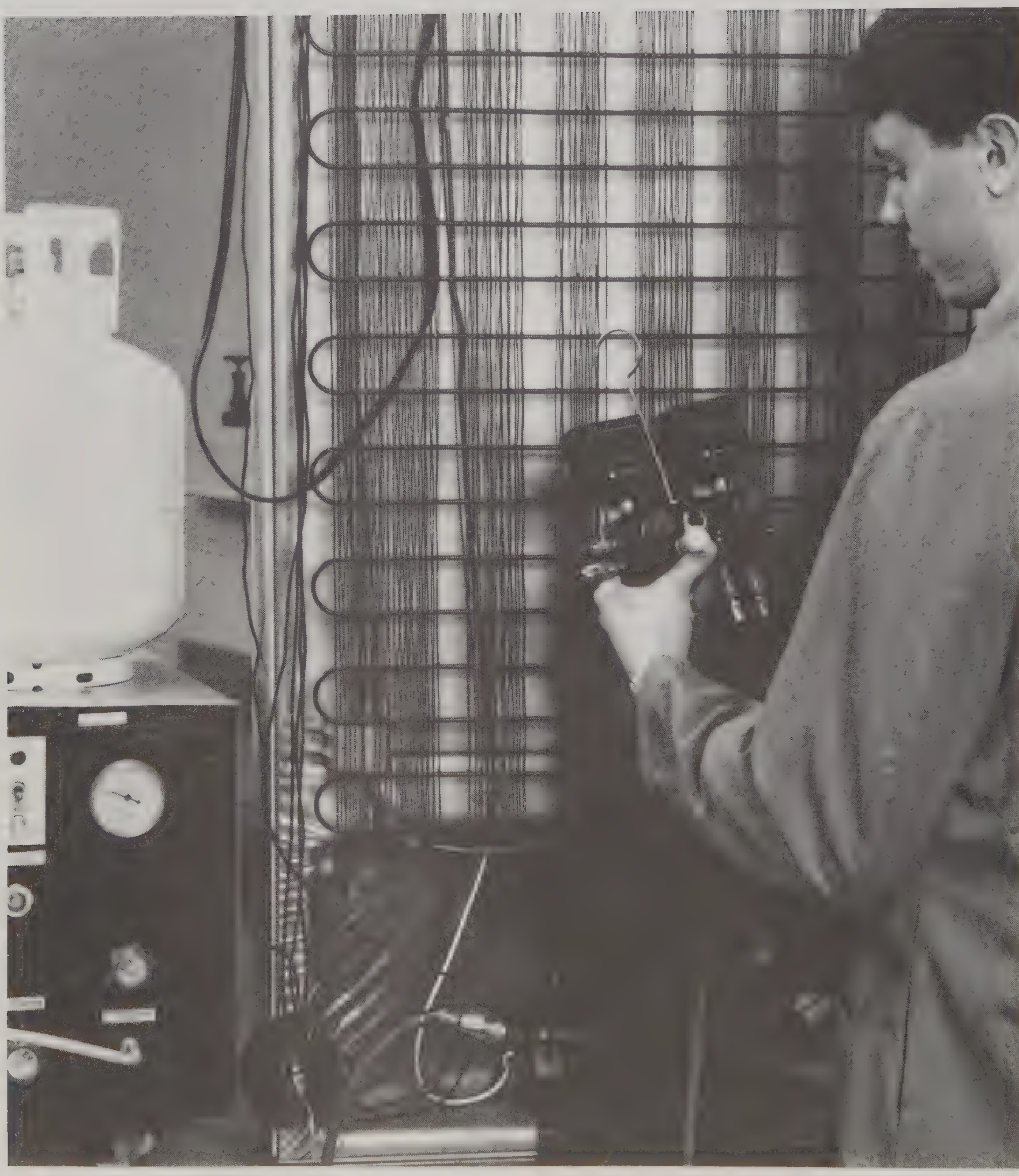
were progressively combined to illustrate how the system provides automatic operation and safety. Electrical components and circuits were illustrated in a step-by-step process.

Standard components were used to add air conditioning to the oil-fueled furnace. The need and purpose of an additional 24V transformer and an isolation relay were explained. The electrical circuits were explained and illustrated by both pictorial and schematic diagrams. Review questions and troubleshooting procedures were included to assist in understanding system operation.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What grade of fuel oil is used in gun-type (atomizing) burners?
2. What two components are operated by the burner motor?
3. Explain the purpose of the burner fan.
4. True or false? The draft control maintains a constant flue pressure.
5. An oil pump is used to increase oil pressure to __________ psig.
6. What is the purpose of the bleed port on a single-stage oil pump?
7. Name the two important ratings marked on nozzles.
8. What are the dimensions for proper electrode placement and gapping?
9. Name the primary and secondary voltages of the ignition transformer.
10. The primary control contains the electrical components necessary for __________ operation of the burner assembly.
11. Which component controls the operation of the furnace blower motor?
12. On most newer furnaces, what device is used for a flame safeguard?
13. The thermostat is connected to the terminals marked __________ on the primary control.
14. Several additional electrical components are required for adding air conditioning to an oil furnace. Name three of them.
15. What is the purpose of the isolation relay?



Training for HVAC technicians should include a thorough grounding in the diagnosis, repair, and adjustment of all types of domestic, commercial, and industrial systems. (Ferris State University)

Chapter 27

ELECTRIC HEAT WITH AIR CONDITIONING

After studying this chapter, you will be able to:

- *Identify components of an electric heating system.*
- *Understand the purpose of each electric heating system component.*
- *Describe proper wiring connections for various heating system components.*
- *Recognize variations in wiring.*
- *Read schematics for electric heating systems.*
- *Describe the operation of two-stage heating systems*
- *Discuss how to isolate control circuits from line voltage circuits.*

NEW WORDS

blower relay	limit switch
combination heating-cooling thermostat	low-pressure safety control
feeder service	outdoor thermostat
fusible link	sequencers
heat relays	two-stage heating system
heating element	two-stage heating thermostat
high-pressure safety control	

HEATING WITH ELECTRICITY

Electric heating involves 100 percent conversion of electrical energy to heat energy. Because no fuel is burned, there is no need for a chimney to vent combustion gases. This provides great flexibility in locating the furnace. Supply air ducts and return air ducts are installed from the furnace to the conditioned space. See Fig. 27-1.

This chapter explains the function of electric heating system components and how they are connected in the electrical circuits. For proper servicing, it is important that you understand the relationship of each component to the others in the system. The system must operate

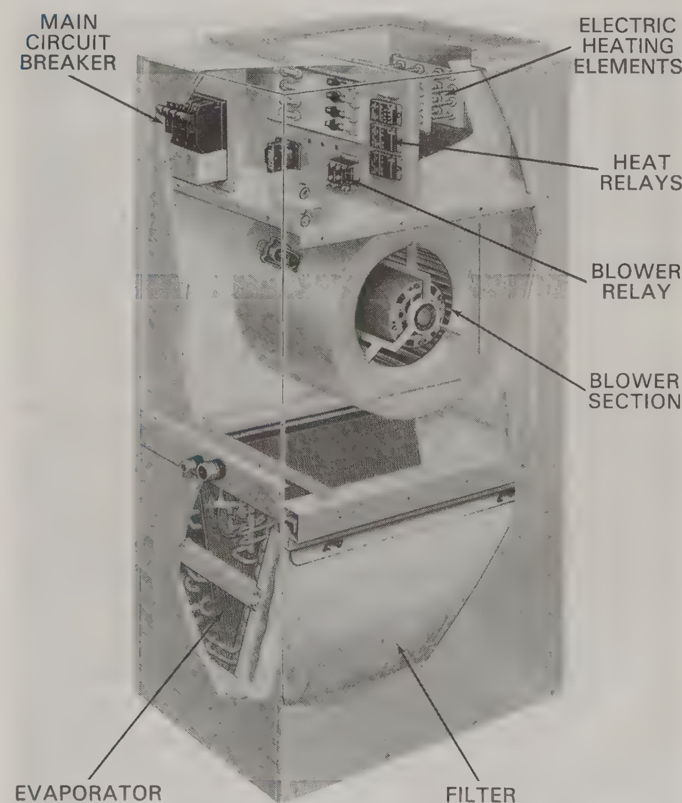


Fig. 27-1. Cutaway view of an electric forced-convection furnace with air conditioning. (Lennox Industries, Inc.)

properly and "automatically" to safely maintain room temperature.

The schematic wiring diagram is used in a step-by-step manner in this chapter to illustrate the relationships and connections for each component in the system. Since you will encounter variations in wiring diagrams on different units in the field, it is important that you thoroughly understand both pictorial and schematic wiring diagrams.

POWER SUPPLY

Electric furnaces require 240V three-wire ***feeder service*** from the main disconnect or load center. This feeder circuit to the furnace must be sized (and fused) in accordance with the National Electric Code (NEC). Electrical requirements are printed on the furnace wiring diagram. The 240V furnace feeder wires are connected to a fused disconnect. The disconnect must be located within sight of the furnace, and must be capable of being locked in the open position. It provides a convenient means of making sure power to the furnace is safely disconnected for service procedures.

The two hot wires and ground wire are run from the load side (bottom) of the fused disconnect to a set of terminals on the fuse block within the furnace enclosure. Some electric furnaces are equipped with a double-pole circuit breaker, rather than a fuse block.

The feeder circuit wires must be enclosed in metal conduit and have watertight connections at both ends. The National Electric Code requires these circuits be grounded in the furnace (not at the disconnect). Most furnaces will provide a ground connection in the control box next to the high-voltage terminals.

This supplies 240V single-phase electrical power, with safety ground, to the unit. See Fig. 27-2. When these electrical supply connections are made, the field-installed line voltage wiring is complete. The remaining 240V circuits (inside the furnace) are factory-installed.

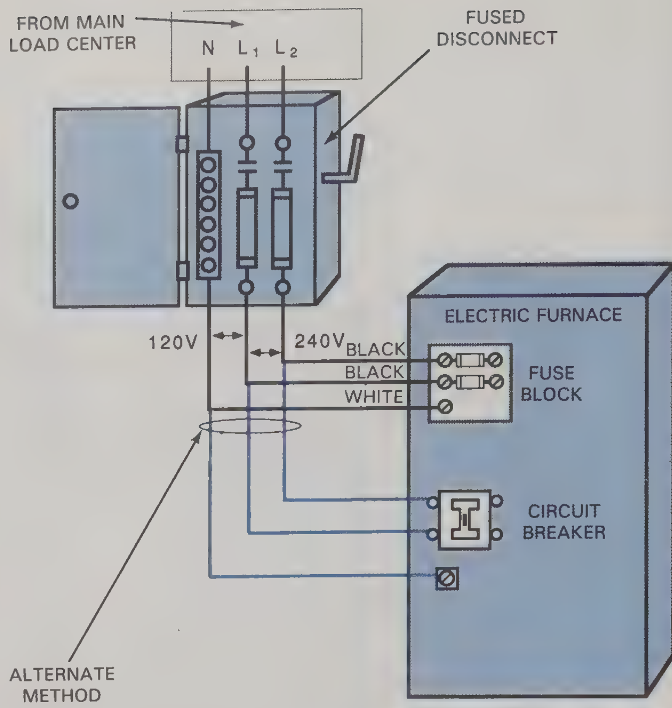


Fig. 27-2. Power supply connections for an electric furnace. Some furnaces use a fuse block, others a double-pole circuit breaker.

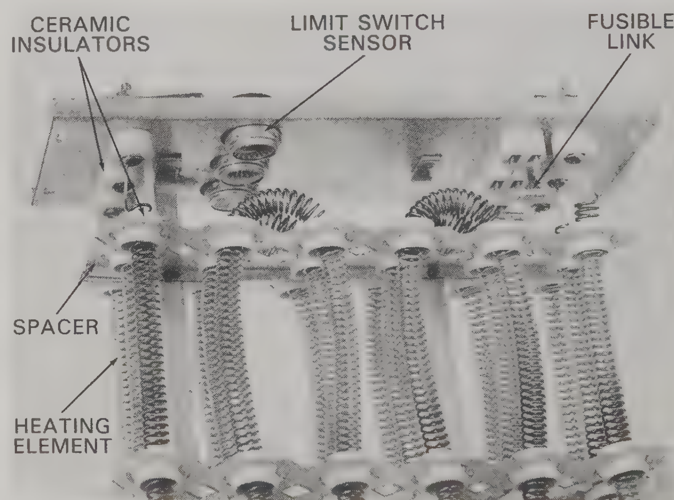


Fig. 27-3. A section of the coiled-wire resistance heating element typically used in electric furnaces. Ceramic insulators prevent metal-to-metal contact that would result in a short circuit. (Lennox Industries, Inc.)

HEATING ELEMENTS

The function of the ***heating element*** is to generate the heat required for the conditioned space. The heating element wire is made of the metals nickel and chromium, and is often referred to by its trade name, Nichrome®. This wire has a built-in resistance to electron flow, with the amount of resistance determined by its length and diameter. Resistance to current flowing through the wire causes it to get hot.

The Nichrome wire is coiled and threaded through a metal frame that has ceramic insulators to prevent metal-to-metal contact (short circuits). The heating element used in furnaces is similar to those found in toasters and electric clothes dryers. See Fig. 27-3. When 240V is applied to the Nichrome element, the current flow causes it to heat up. This heat is transferred to the air that is being circulated through the furnace by the blower.

Furnace heating elements are normally sized at 5 kilowatts (kW), or 5000 watts. There are 3.415 Btus per watt, so the heat output of such an element would be 17,075 Btu/hr. ($5000 \times 3.415 = 17,075$). To provide the necessary amount of heat, several elements may be required. A fuse must be installed in each power supply leg to each element. Since a 5.0 kW element draws about 20A amps, a 30A fuse is required in each leg. The

fuse monitors the amount of current flow in the heating element branch circuit. Excessive current flow will cause the fuse to burn out (open), and thus protect the circuit wiring.

CAUTION: When a fuse burns out, it should be replaced only with the correct size fuse shown on the unit wiring diagram. Before replacing a fuse, always find and correct the fault that caused it to burn out.

LIMIT SWITCH

The purpose of the ***limit switch*** is to deenergize the heating element if the temperature exceeds the switch setting. The limit switch uses a normally closed, disc-type bimetallic sensor enclosed in a metal housing. The limit switch is mounted on the frame of the heating element. See Fig. 27-4.

Normally, air being circulated through the furnace removes heat and maintains proper temperatures. If airflow is not adequate, furnace temperature will rise rapidly. The bimetallic element will sense the excessive heat and cause the NC contacts to open. This will deenergize the heating element until the furnace cools down. Once the element cools, the bimetallic element closes its contacts and permits the heating element to function again. This is called "cycling on the limit switch." Dirty air filters and blower motor failures are the primary causes of overheating.

The limit switch has a temperature differential built in between the "open" and "close" setpoints. The "close" setpoint is normally 35°F (19°C) cooler than the "open" setpoint. For instance, if the limit switch opens at 160°F (71°C), it will not close until the temperature is reduced to 125°F (52°C). This differential setting prevents the heating element from short-cycling.

Each heating element contains its own safety controls (limit switches and fusible links) which are unaffected by the operation of other elements. This eliminates the need for safety limit controls in the control circuit. Heating elements are not position-sensitive, and can be mounted in any position. **CAUTION:** Limit switches are sized for different heating element applications. The different "open" setpoints may vary from 130°F to 190°F (54°C to 88°C). A replacement limit switch must have the same ratings as the original.

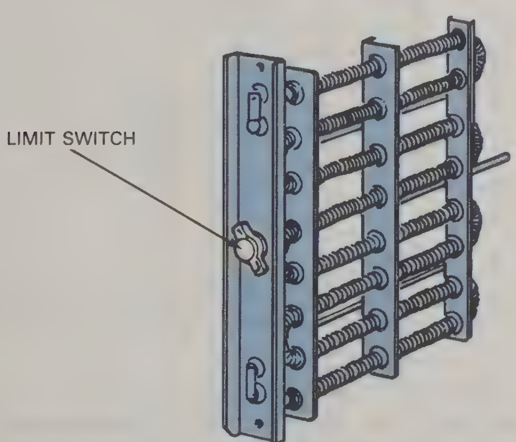


Fig. 27-4. The limit switch is located on the frame of an electric heating element. It has a bimetallic element sensor that opens the circuit when the temperature exceeds the high limit.

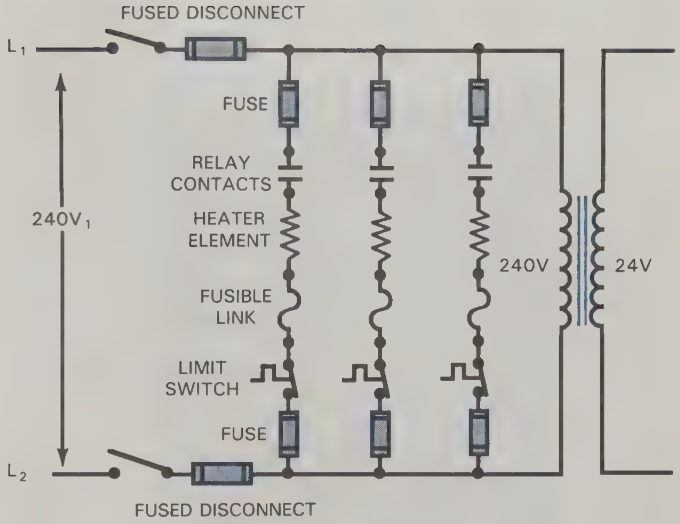


Fig. 27-5. Schematic of the line voltage connections for a group of three heating elements.

FUSIBLE LINK (THERMAL FUSE)

Heating elements also contain a ***fusible link*** or thermal fuse to protect them against burnout if the limit switch fails. Each heating element has a factory installed fusible link connected in series in one of the "hot legs. If the temperature of the element becomes abnormally high, the link will melt, opening the line voltage circuit.

Fig. 27-5 is a schematic of the line voltage (24OV) circuit supplying power to three heating elements. This wiring is factory installed and located inside the furnace cabinet.

HEAT RELAYS AND SEQUENCERS

Electric furnaces are designed so that the heating elements are energized one or two at a time, in sequence. Energizing all heaters at one time would place an overwhelming electrical demand on the power supply. Devices used to stage the elements on and off are called ***heat relays*** or ***sequencers.*** See Fig. 27-6. Both devices use a bimetallic element for the normally open switch, and include a small heater to activate (close) the switch.

Heat relays normally contain one or two switches, and are used to stage a single element on or off. Thus, one heat relay is required for each element. The heat relay that controls the first heating element to be energized must have two switches: one to turn on the heating element, and one to turn on the blower motor. Sequencers may contain several switches controlled by a small heater.

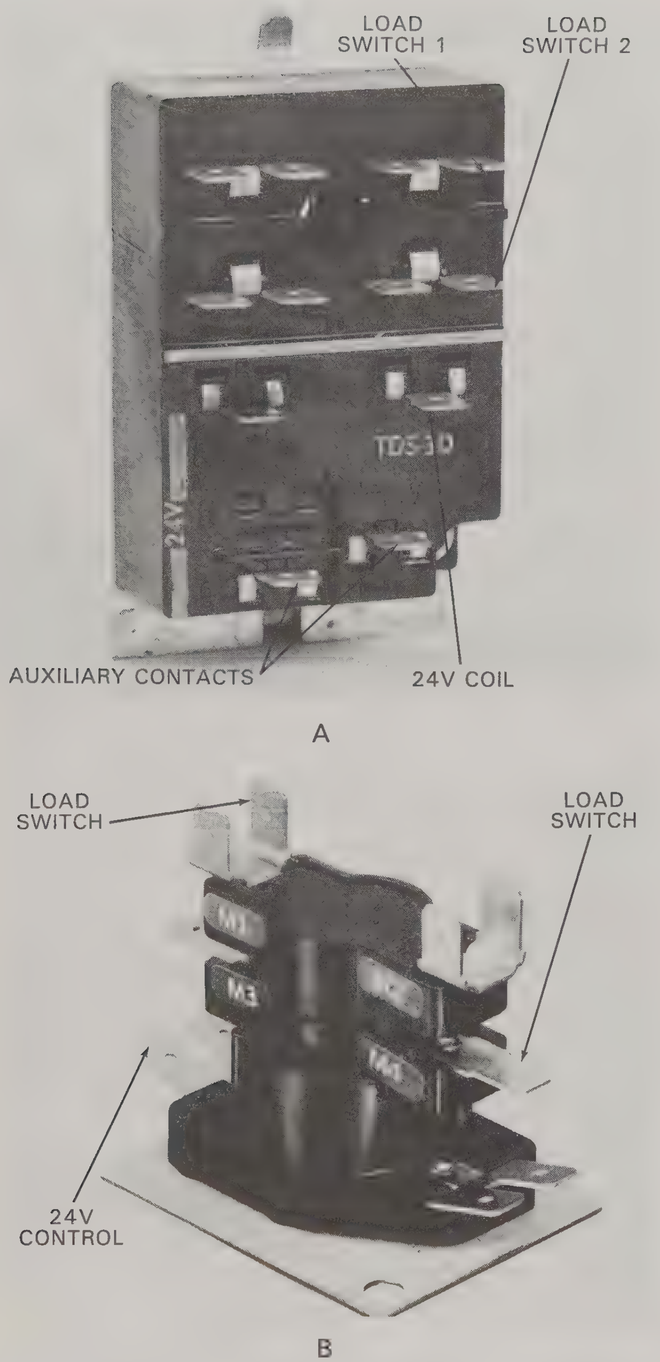


Fig. 27-6. Devices used to energize heating elements in sequence. A–Heat relay. (Lennox Industries, Inc.) B–Heating sequencer. (White-Rodgers)

A sequencer operates the same way as a heat relay, but may automatically control staging of multiple elements, as well as the blower motor. See Fig. 27-7.

Heat relays controlling multiple heating elements

When multiple heating elements are used, the sequence of operation is as follows:

Upon a call for heat from the thermostat, a 24V circuit is completed to the small heater in heat relay 1. After about 20 seconds, heat from the small heater will cause the switches in that heat relay to close. One switch energizes the first heating element; the other switch energizes the blower motor. See Fig. 27-8.

Heat relay 2 contains a 240V heater that is connected in series with the first heating element. When that heating element is energized, so is the small heater in relay 2. After a time delay, the relay 2 contacts close. These contacts are connected in series with the second heating element. The small heater for relay 3 also is connected

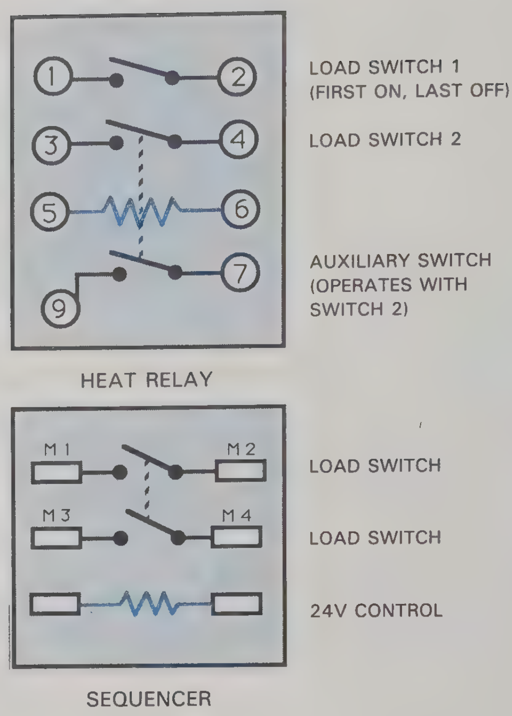


Fig. 27-7. Both the heat relay and the sequencer use a small heater to close load switches.

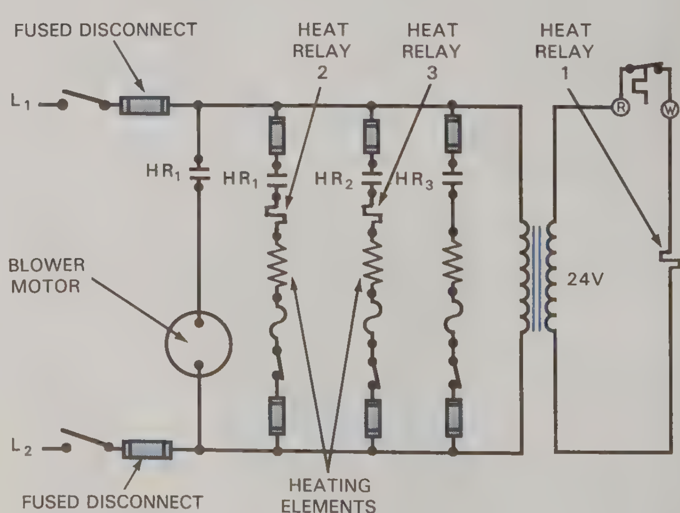


Fig. 27-8. When the thermostat calls for heat, a small resistance heater in relay 1 will cause the normally open relay contacts (labeled HR_1 on this schematic) to close, energizing the first heating element and the blower motor. Heat relays 2 and 3 will, in turn, energize the remaining two heating elements.

in series with the second heating element. After a time delay, the relay 3 contacts close. These contacts are connected in series with the third heating element. Thus, each heating element is staged to come on, one after the other. The time interval between stages can be 15 to 45 seconds.

When the thermostat is satisfied and "opens," the heating elements will stage themselves off in reverse order. Time must be allowed for the small relay heaters to cool. The heat anticipator inside the thermostat compensates for this delayed shutdown and additional heat. As described in Chapter 25, the heat anticipator causes the thermostat to open its contacts just before proper room temperature is achieved.

TWO-STAGE ELECTRIC HEAT

A ***two-stage heating system*** tries to match the furnace's heating ability to the actual heating requirement. This popular energy saving feature is accomplished by controlling the furnace capacity. The first stage of a ***two-stage heating thermostat*** energizes the first bank of heating elements. If more heat is needed than the first stage can supply, the thermostat then energizes a second bank of heating elements.

To illustrate this staging of heating elements, an electric furnace with five heating elements will be used. The first stage of heat (elements 1, 2, and 3) operates when the thermostat calls for heat during periods of moderate outdoor temperatures. The second stage of heat (elements 4 and 5) is energized only during periods of extreme cold, when the first stage cannot satisfy the demand. Energy savings result because not *all* the elements are energized every time there is a call for heat. See Fig. 27-9.

The first stage is always energized before the second stage of heat. The second stage is always deenergized before the first stage turns off. A secondary (temperature-sensitive) fan control is often added to keep the blower energized until all heat is dissipated from the furnace after shutdown.

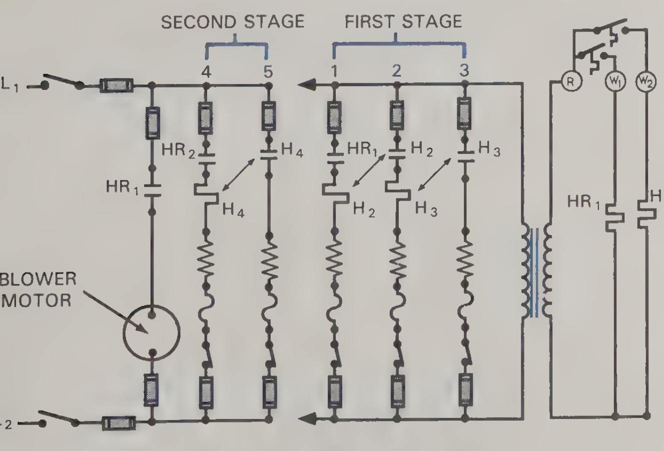


Fig. 27-9. An electric furnace with a thermostat controlling two heat stages. The first stage (heating elements 1, 2, and 3) is supplemented by the second stage (elements 4 and 5) when additional heating is needed.

TWO-STAGE HEATING THERMOSTAT

The two-stage heating thermostat has two separate mercury-bulb heating switches. This eliminates the need for two separate thermostats. One mercury switch controls the first stage of heat and the second controls the second stage of heat. The two mercury switches open and close at different temperature setpoints. Separate heat anticipators are included for each switch. See Fig. 27-10.

Power supply from the transformer is connected to terminal R on the thermostat. This supplies 24V power to each mercury switch. One controls power to the W_1 terminal (first-stage heating), and the other controls power to the W_2 terminal (second-stage heating).

When room temperature drops to the thermostat setpoint, the thermostat contacts controlling power to W_1 will close. First-stage heating is energized. If heat from the first stage is sufficient to prevent further temperature drop, the second stage remains off. If the room temperature drops another 1 1/2 to 2 degrees, however, the contacts in the second mercury switch will close. This energizes the second-stage heating elements.

When room temperature rises, the system deenergizes the stages in reverse order: the second stage shuts off first, then the first stage shuts off. Fig. 27-11 illustrates a

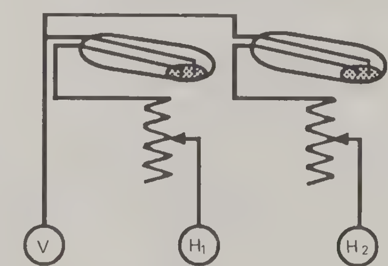


Fig. 27-10. A two-stage heating thermostat contains two mercury switches. One controls first-stage heating, the other controls the second-stage elements. Each switch is equipped with a heat anticipator.

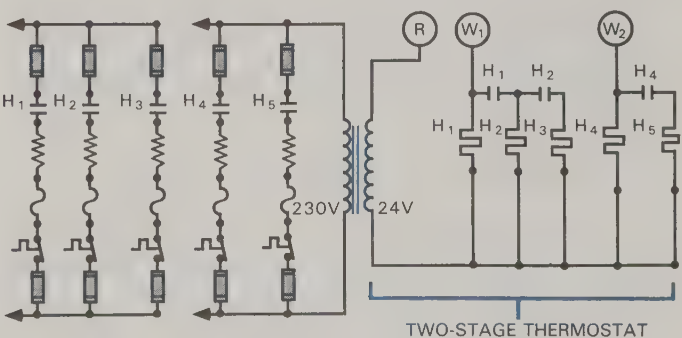


Fig. 27-11. A two-stage (five-element) heating system controlled by a two-stage thermostat. The relay heaters are in the 24V circuit, but the contacts are part of the 240V circuits.

two-stage heating thermostat connected so that it controls five heating elements. Notice that the small heaters in each heating relay are in the 24V circuit, while the relay *contacts* are in the 240V circuit. Connecting the relay heaters in the 24V circuit is another method of using heat relays to step-start heating elements. The heaters used in heat relays are labeled 240V or 24V and *must* be connected to the correct voltage. They are not interchangeable.

OUTDOOR THERMOSTAT

Another method used to stage two banks of heating elements is to use an ***outdoor thermostat*** in conjunction with a regular (single-stage) indoor thermostat. The outdoor thermostat is used to monitor external air temperature, since more heat is usually needed when the outdoor air gets colder. The thermostat contacts open on rising temperature and close on falling temperature.

The outdoor thermostat controls the second bank of heating elements. The first stage heating elements are cycled on and off by the indoor heating thermostat. When the outdoor temperature is above the outdoor thermometer's setpoint, the first stage heating should be able to satisfy the heating needs of the building. The outdoor thermostat cannot energize the second stage unless the indoor thermostat is calling for heat, *and* the outdoor temperature is below the setpoint of the outdoor thermostat. See Fig. 27-12.

COOLING BLOWER RELAY

A ***blower relay*** is required when adding air conditioning to an electric furnace. Blower controls for the heating cycle energize the blower when heat is produced. A separate relay must be used to energize the blower during the cooling cycle. The coil on the blower relay is 24V and is controlled from terminal G on the indoor thermostat. When the thermostat's manual fan switch is set for AUTO, terminal G automatically receives 24V when the thermostat calls for cooling. This energizes the blower relay coil and closes its switch. The blower relay switch is connected in series with the blower motor. See Fig. 27-13.

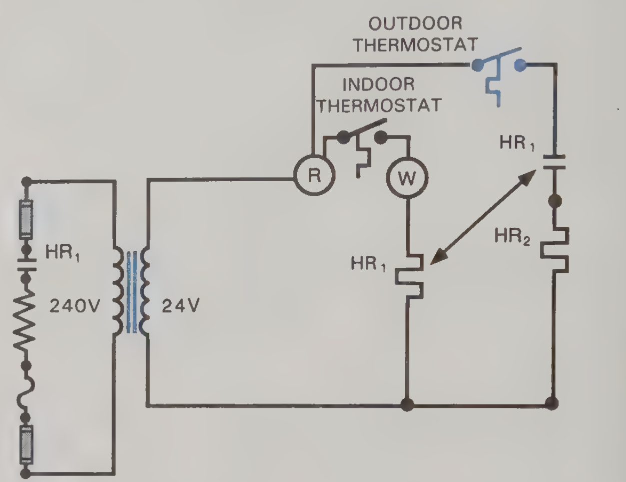
Setting the manual fan switch to CONT causes the blower relay coil to be energized continuously. This permits operation of the blower motor at any time, regardless of thermostat settings.

TWO-SPEED BLOWER MOTOR

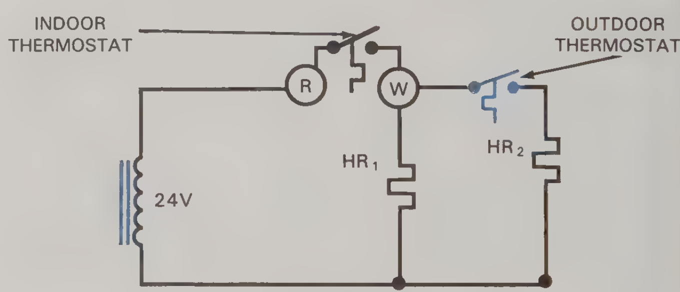
A two-speed blower motor is often used to provide proper airflow through the furnace. Low speed (1050 rpm) is normally used for the heating cycle, and high speed (1800 rpm) for the cooling cycle. Fig. 27-14 illustrates the wiring for a two-speed blower motor.

The blower relay often uses a single-pole, double-throw switch. One set of contacts is NO and the other is NC. See Fig. 27-15. The NC switch is connected in series with power supply to the blower motor for the heating cycle (low-speed). The NO switch is connected in series with the blower motor's high-speed windings. See Fig. 27-16.

The normally closed switch permits low-speed motor operation during the heating cycle, but acts as a "lock-out" when the blower operates at high speed (cooling).



OUTDOOR THERMOSTAT SCHEMATIC 1



OUTDOOR THERMOSTAT SCHEMATIC 2

Fig. 27-12. An outdoor thermostat can be used in conjunction with an indoor thermostat to control a two-stage heating system. Two different circuit configurations are shown. Both accomplish the same result, energizing the second-stage heating elements when outdoor temperature drops below the outdoor thermometer's setpoint.

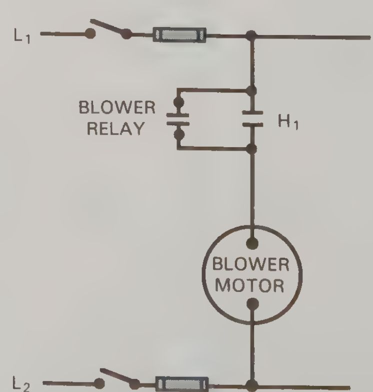


Fig. 27-13. The blower relay controls the blower motor during the cooling cycle.

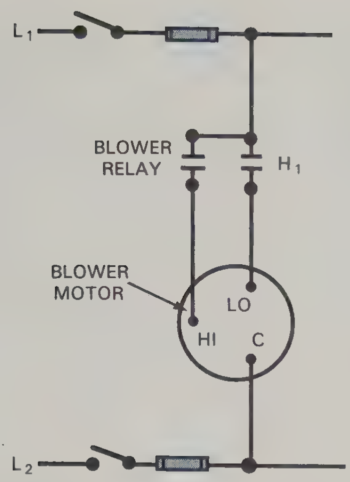


Fig. 27-14. A blower relay connected to a two-speed blower motor.

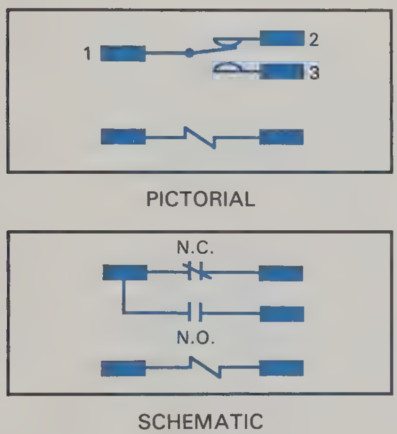


Fig. 27-15. The blower relay used with a two-speed blower motor has a single-pole, double-throw switch. As shown in both pictorial and schematic forms, one contact is normally closed, and the other is normally open. The NC contact is in series with the blower's low speed (heating) winding.

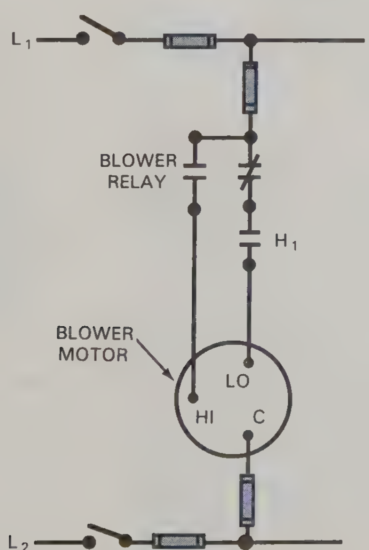


Fig. 27-16. Schematic of a blower relay with a single-pole, double-throw switch being used with a two-speed blower motor.

The normally open switch functions in just the opposite manner, permitting high speed operation during the cooling cycle, but acting as a "lockout" when the motor operates at low speed (heating). This method prevents both speeds from being energized at the same time.

COMBINATION HEATING-COOLING THERMOSTAT

A ***combination heating-cooling thermostat*** is required when adding air conditioning to an electric furnace system. This provides control of both heating and cooling from one device (the thermostat). The heating switch closes on a temperature fall, and the cooling switch closes on a temperature rise. When the cooling switch closes on a temperature rise, 24V power is supplied to terminal Y (yellow wire) on the thermostat. A wire is connected from terminal Y to the coil on the compressor contactor. The other side of the contactor coil is connected directly to the neutral side of the 24V transformer. See Fig. 27-17.

When the thermostat's cooling switch closes on a temperature rise, 24V power is supplied to both terminal Y and terminal G. Terminal G energizes the blower relay and turns on the blower fan. Terminal Y energizes the compressor contactor coil and the cooling system turns on. When the thermostat's cooling switch opens on temperature fall, current flow through the 24V control circuit to the G and Y terminals stops. The blower motor and compressor immediately stop running because the blower relay coil and the contactor coil are deenergized. This opens the switches located in the high-voltage circuit.

RESIDENTIAL HIGH-PRESSURE SAFETY CONTROL

Many residential air conditioning units are equipped with a ***high-pressure safety control.*** See Fig. 27-18. This high-pressure control is attached directly to the hot gas

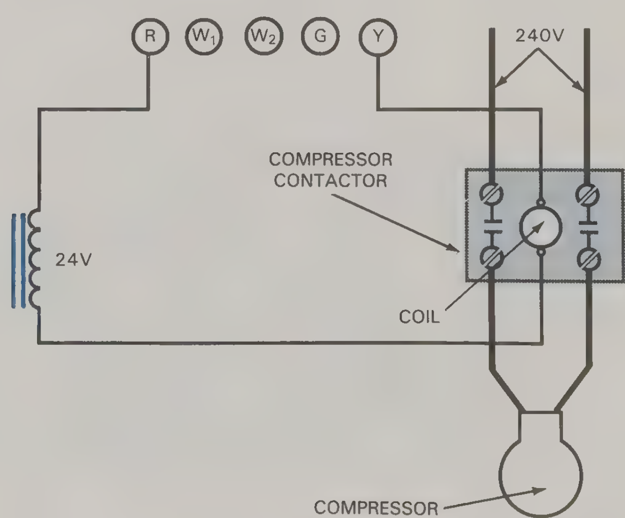


Fig. 27-17. A heating-cooling thermostat controls operation of the compressor contactor coil.

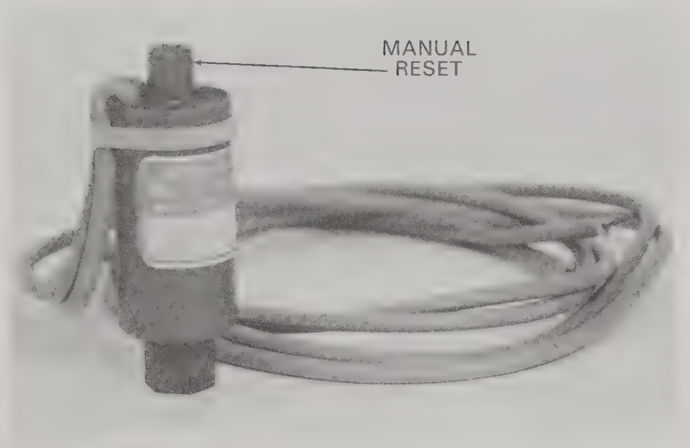


Fig. 27-18. High-pressure safety control for residential air conditioning. (Lennox Industries, Inc.)

discharge line. If discharge pressure exceeds the factory setting (about 400 psig or 2758 kPa), an internal switch opens. The two factory installed wires are connected to place the switch in series with the 24V power supply to the contactor coil.

The discharge pressure acts against a diaphragm that is balanced by a calibrated spring inside the control. If discharge pressure exceeds the setpoint, it overcomes the spring tension and opens the contacts. This stops the compressor. This safety control normally has a manual reset. When the control is tripped open, the service technician must first correct the cause of high head pressure (such as lack of condenser air, overcharge, or air in the system).

LOW-PRESSURE SAFETY CONTROL

Many residential air conditioning units are also equipped with a ***low-pressure safety control,*** Fig. 27-19. The low-pressure safety control is attached directly to the suction line. The suction works against a spring-loaded diaphragm that is mechanically linked to the normally closed contacts. If suction pressure falls below the control setpoint, the spring opens the contacts. Low suction pressure could be caused by dirty air filters, blower motor problems, a low refrigerant level, or poor flow of refrigerant (a restriction).

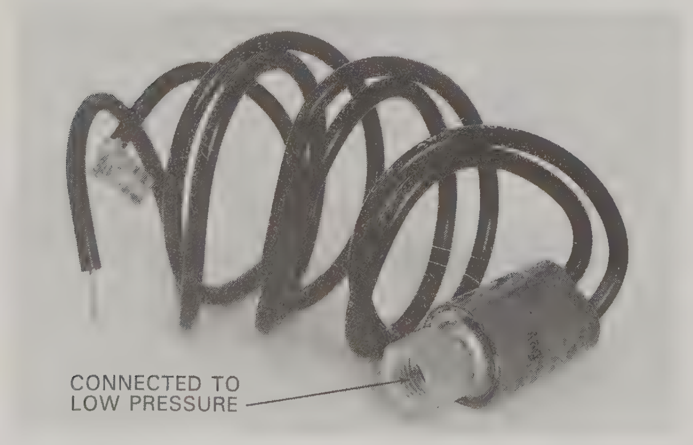


Fig. 27-19. A low-pressure safety control used for residential air conditioning installations. (Lennox Industries, Inc.)

The low-pressure safety control is intended to protect the compressor against low suction pressures. The control setpoints are established by the factory, and reset is automatic. Installation involves connecting two factory installed wires to place the switch in series with the compressor contactor coil. See Fig. 27-20.

See Fig. 27-21 for the schematic and pictorial diagrams for a typical two-stage electric furnace and single-stage air conditioning system. Notice that second stage heating cannot be energized unless the first stage is also energized. This is accomplished by heat relay HR_{4A}.

TROUBLESHOOTING ELECTRIC FURNACES

As noted in previous chapters, systematic troubleshooting of heating and cooling systems requires skills that must be cultivated and developed. A service call tests the technician's knowledge, mechanical skills, and ability to observe and interpret information. Good troubleshooting requires the use of information to make a conclusion. Hasty decisions, or wrong information, results in wrong conclusions. Troubleshooting involves using step-by-step procedures and a *process of elimination* to pinpoint the problem. There are five important steps involved in systematic troubleshooting:

1. Know what the equipment *should do*.
2. Know what the equipment is *doing*.
3. Know what the equipment is *not* doing.
4. Eliminate areas that *are* functioning properly.
5. Concentrate on areas that are *not* functioning properly.

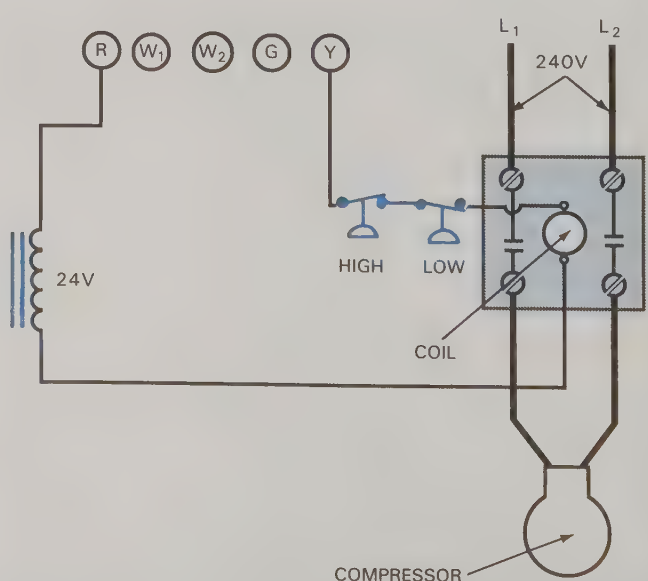


Fig. 27-20. High-pressure and low-pressure safety controls are connected in series with the compressor contactor coil.

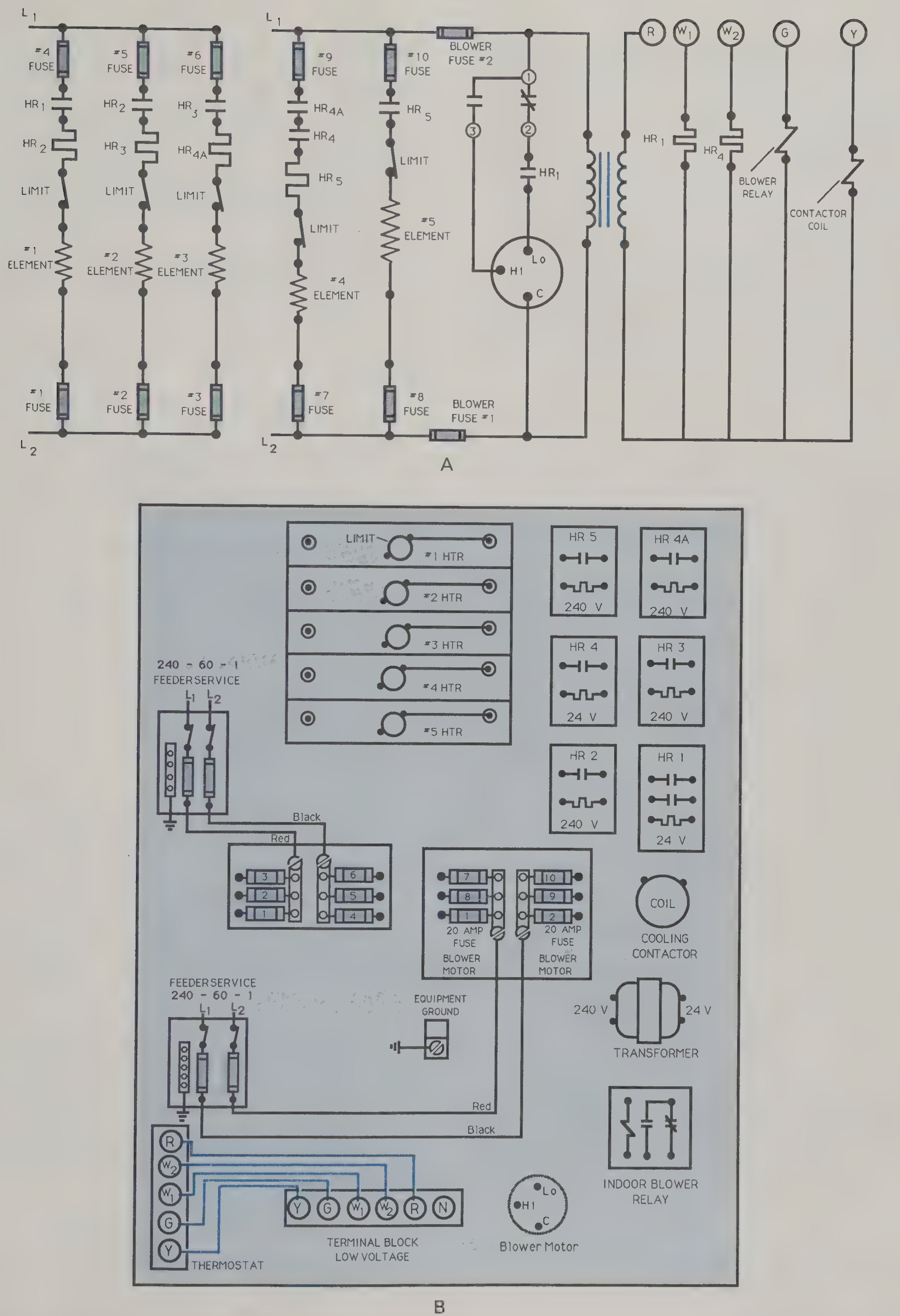


Fig. 27-21. A typical two-stage electric furnace with a single-stage air conditioning system. A–Schematic diagram. B–Pictorial diagram.

The customer's complaint usually helps narrow the problem to a specific area. These complaints fall into one of six possible headings:

- No heat.
- Not enough heat.
- Too much heat.
- Noise.
- Odor.
- Excessive operating cost.

A question or two to the homeowner, plus a few observations of the equipment, should aid in the process of elimination. By listening, observing, and testing, the technician discovers clues that point to the exact problem. Some of the most likely causes are listed under each problem area.

NO HEAT

- Wrong thermostat settings.
- Broken or loose thermostat wires.
- Defective thermostat.
- No power supply to furnace (check fuses, circuit breakers).
- Low voltage at transformer secondary (less than 22V).
- Low voltage at transformer primary (more than 10 percent drop).
- Defective transformer (check fuse).
- Defective heating elements.
- Blown thermal fuse or fusible link.
- Defective heat control relay.
- Defective heating contactor.

NOT ENOUGH HEAT

Second stage not operating.

- Wrong thermostat settings.
- Wrong heat anticipator adjustment.
- Vibration at thermostat.
- Thermostat influenced by warm air.
- Defective thermostat.
- Wrong setting on outdoor thermostat.
- Wrong location of outdoor thermostat.
- Defective outdoor thermostat.

Some heating elements not operating.

- Sequencer not operating.
- Defective high limit control.
- Defective second-stage relay.
- Defective second-stage contactor.

TOO MUCH HEAT

- Thermostat not level.
- Heat anticipator set too high.
- Thermostat in cold draft.
- Defective thermostat.
- Defective heat relay.
- Control circuit shorted.

NOISE

- Loose blower bearings.
- Blower bearing dry and squeaking.
- Blower wheel off-center.
- Loose V-belt.
- Loose running gear and mounts.
- Filter caught in running gear.
- Loose cabinet panels.
- Loose relay mountings.
- Noisy contactor (replace).
- Humming transformer (replace).
- Loose ductwork.

ODOR

- Dirty air filters.
- Stagnant water or sludge in humidifier.
- Control transformer burning out.
- Overheated wiring or overloaded circuit.
- Dirty heating elements.

EXCESSIVE COST OF OPERATION

- Insufficient home insulation.
- Excessive air leakage from home (fireplace, vents, etc.).
- Wrong fan control settings.
- Defective blower motor with high amperage.
- Blower belt too tight.
- Dirty blower wheel.
- Wrong humidity.

SUMMARY

This chapter explained the purposes and wiring connections for commonly used components of residential electric heating systems. Single-stage heating systems were described and their wiring connections were illustrated. For energy conversation, many electric heating systems have two stages of heat. Such systems were explained and two methods of controlling the stages were illustrated. The operation and proper wiring connections for two-stage heating thermostats were explained.

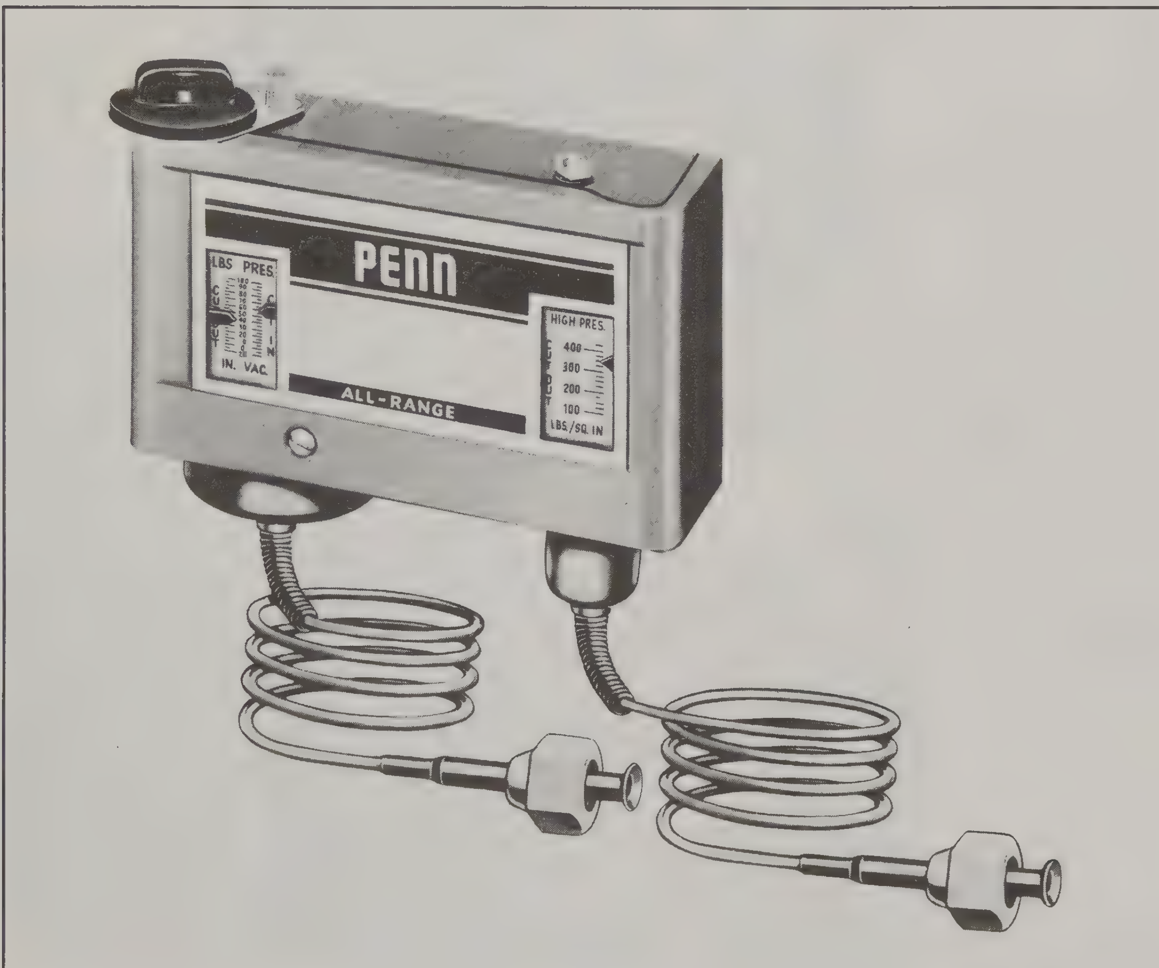
The electrical connections used when air conditioning is added to the electric furnace were described. Variations in safety controls for residential air conditioning were discussed. The purpose and wiring connections for the single-pole, double-throw blower relay were described, and its use with two-speed blower motors was explained.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. Do electric furnaces require a chimney?
2. Electric heating elements normally require a ________ power supply.

3. What are the two requirements for a fused disconnect used with an electric forced convection heating system?
4. The special wire used for heating elements is made from the metals ________.
5. ________ insulators are used to separate the heating element wire from the metal frame.
6. Why is a fuse required in each power supply leg to each element?
7. The factory installed limit switch will deenergize the heating element because of excessively high ________.
8. If the limit switch fails, what back-up device provides the necessary protection?
9. What two devices are commonly used to step-start heating elements?
10. True or false? Both the heat relay and the sequencer use a small heater to operate a bimetallic switch.
11. Furnace ________ is controlled by using two stages of electric heating.
12. A two-stage heating thermostat has two separate mercury ________.
13. Is an outdoor thermostat used to control the first stage or the second stage of a two-stage electric heating system?
14. When air conditioning is added to an electric heating system, what additional relay must be installed?
15. Name three causes of high head pressure.



A dual-pressure motor control, used primarily in commercial refrigeration and air conditioning systems, combines a low-pressure control and a head-pressure (high-pressure) safety control. This saves time and money because double protection is provided with one control. Wiring connections are simplified because the control has just two terminals. (Penn Controls)

Portable refrigerant recovery and recharging systems like this one are easily wheeled into place on the job site. This unit is designed to recover, recycle, and recharge Refrigerant R-134a. (Kent-Moore)

Chapter 28

HEAT PUMPS

After studying this chapter, you will be able to:
- *Describe the operating principles of the heat pump.*
- *Recognize and explain the purpose of major heat pump components.*
- *Define the terms coefficient of performance, energy efficiency ratio, and balance point.*
- *Describe the principle and operation of the reversing valve.*
- *Identify and describe types of refrigerant flow controls.*
- *List types of defrost controls and describe their operation.*
- *Describe the operation of thermostats used on heat pumps.*
- *Read and understand heat pump schematics.*
- *Discuss the principles of systematic troubleshooting.*

NEW WORDS

auxiliary heat	heat content
balance point	heat pump
bypass line	indoor coil
coefficient of performance (COP)	low-ambient thermostat
compliant scroll compressor	outdoor coil
defrost cycle	outdoor fan and defrost relay
emergency heat switch	outdoor thermostat
energy efficiency ratio (EER)	pilot valve
	restrictor
	reversing valve

RESIDENTIAL HEAT PUMPS

The ***heat pump*** is an air conditioning system capable of reversing refrigerant flow so that it can function as either a cooling source or a heat source. When the refrigerant flow is reversed for the heating cycle, the ***outdoor coil*** becomes an evaporator instead of a condenser, and the ***indoor coil*** becomes a condenser, rather than an evaporator. During reverse flow, the outdoor evaporator absorbs heat from ambient air and discharges this heat into the home by means of the indoor condenser.

The familiar window air conditioning unit can be used to illustrate the operation of a heat pump. In the summertime, the air conditioner absorbs heat from inside the room and discharges this heat outside. When winter arrives, you could remove the unit from the window, turn it end-for-end, and reinstall it. The unit would then absorb heat from the outside air and discharge this heat into the room.

The heat pump is designed to accomplish the same purpose by using a four-way ***reversing valve*** to control direction of refrigerant flow. During the cooling cycle, the heat pump functions like an ordinary air conditioner. The indoor coil is an evaporator and the outdoor coil is a condenser. When the unit is switched to the heating cycle, however, the reversing valve changes refrigerant flow. As already noted, the indoor coil becomes the condenser and the outdoor coil is converted to an evaporator.

The heat pump is *not* simply an air conditioner with reverse flow capability, however. It is a precisely engineered system designed to heat and cool with similar components. In appearance, it looks like a conventional air conditioning system. See Fig. 28-1.

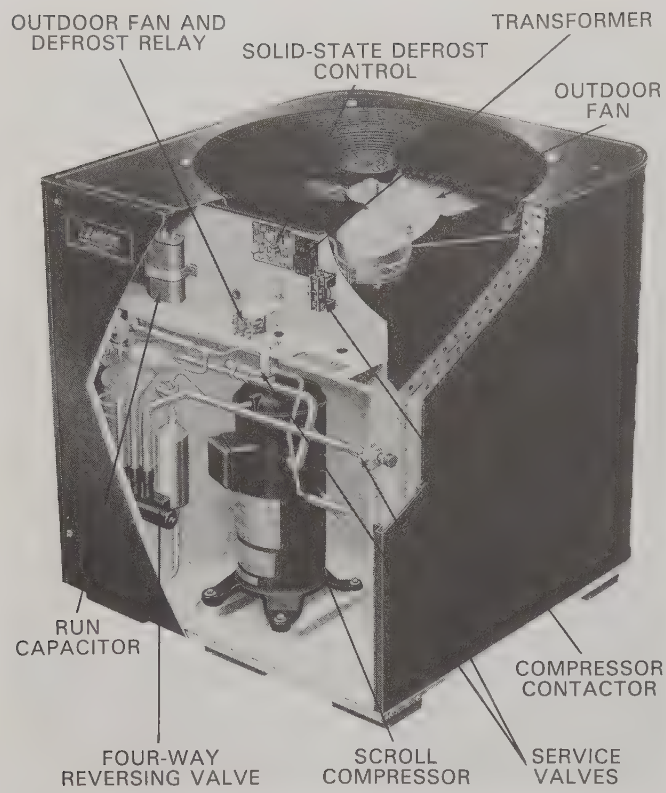


Fig. 28-1. Cutaway view of a residential heat pump. (Lennox Industries, Inc.)

This chapter will describe how an air-to-air heat pump works, explain the operation of various components, and discuss the application of heat pumps in residential situations.

COEFFICIENT OF PERFORMANCE

Outside air always contains a certain amount of heat (measured in British thermal units, or Btu). Air does not lose *all* its ***heat content*** until it reaches absolute zero (-460°F or -273°C). The heat pump is designed to extract heat from outdoor air, and do it more efficiently than electric resistance heating. Electric resistance heat is considered to be 100 percent energy-efficient in converting electrical energy to heat energy. For every kilowatt of electricity used, an electric resistance heating system will produce 3412 Btu of heat energy. A heat pump can *improve upon* this energy efficiency.

The measurement of heat output (Btu) divided by its power input (Btu/watt) is called the ***coefficient of performance (COP).*** A heat pump with a COP of 3.00 will produce three times more Btu of heat for the same electrical energy input as electric resistance heating elements. For example, a heat pump that produces 50,000 Btu at 60°F (16°C) outside air temperature uses about 4400 watts (4.4 kW) of electrical energy. Electric resistance heat using the same amount of electrical energy (4.4 kW) would produce only 15,012 Btu. Therefore, at 60°F outdoor air temperature, the heat pump has a COP of 3.32. This means that it is more than three times as energy-efficient as electric resistance heat. As outdoor temperature falls, however, less outdoor heat is available and the heat pump COP is reduced (it becomes less energy-efficient).

ENERGY EFFICIENCY RATIO

Another term used to describe the energy efficiency of all types of appliances is the ***energy efficiency ratio (EER)***. The EER is stated as the ratio of energy produced (output) to energy used (input). This method provides the consumer with the relative operating cost of an appliance. The higher the EER, the more energy-efficient the product. In the preceding example of COP, the heat pump produced 50,000 Btu with an input of 4400 watts at an outdoor air temperature of 60°F. Dividing 50,000 by 4400 gives an EER of 11.36.

At an outdoor air temperature of 0°F (-18°C), heat pump efficiency is greatly reduced. With an output of 16,000 Btu and 4400 watts of input, the EER at 0°F becomes 3.64 (16,000 ÷ 4400 = 3.64).

BALANCE POINT

Heat pumps require accurate load calculations for building heat loss and heat gain. After accurate heat loss and heat gain has been figured, the balance point of the heat pump is determined.

The ***balance point*** of a heat pump is that point where the *heating ability* of the device equals the *heat loss* of the building. See Fig. 28-2. The balance point will vary according to outdoor temperature, building design, building construction, or other factors, but will fall between 30°F and 40°F (-1°C and 4°C). When the balance point is reached the heat pump runs continuously.

When outdoor air temperature is *above* the balance point of the system, the heat pump can readily make up for heat loss. When outdoor air temperature is *at or below* the balance point, auxiliary (supplementary) heat must be supplied. ***Auxiliary heat*** is usually provided by staging electric heating elements. When outdoor air temperature drops to 15°F (-9°C), the heat pump is normally turned off and the home is heated by a conventional electric, gas, or oil furnace.

HEAT PUMP APPLICATION

Guesswork has no place in selecting equipment and designing a heat pump system. Although the heat pump looks much like a conventional air conditioning unit, its components must operate equally well in both heating and cooling modes. This often requires special engineering of the heat pump components to withstand adverse conditions. A defrost cycle, more electrical controls, additional safety devices and other components are required to permit operation in both modes.

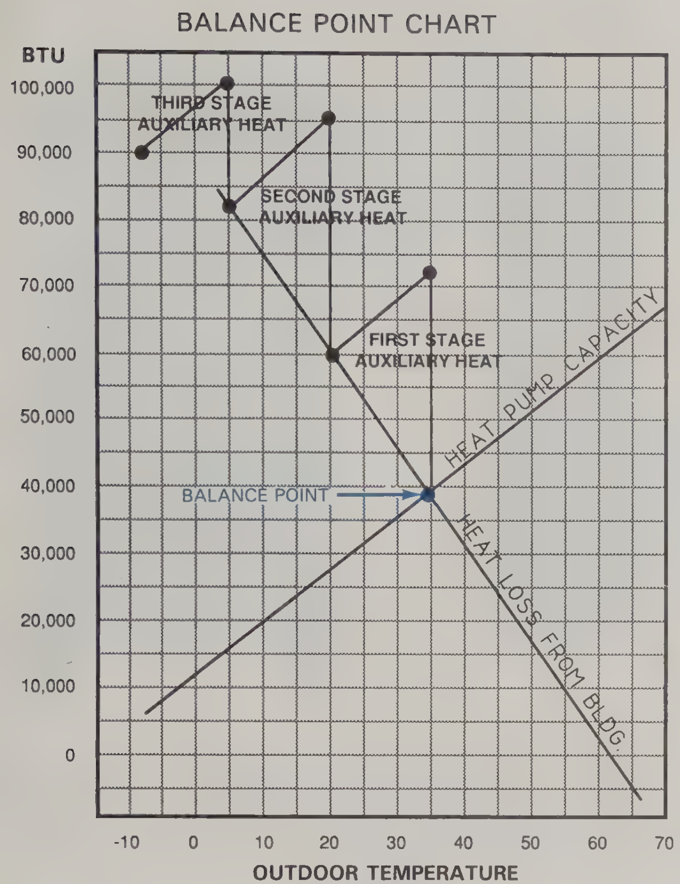


Fig. 28-2. This chart shows the balance point of a heat pump. That is the point where the heat pump capacity and the building heat loss are equal.

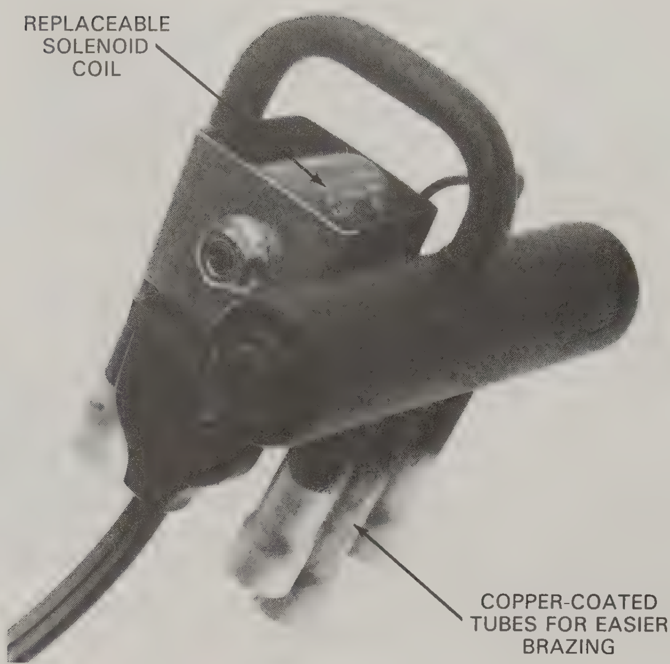


Fig. 28-3. A reversing valve makes it possible to alternate heating and cooling modes of the heat pump by reversing the flow of refrigerant. The valves are available in various sizes to match different heat pump capacities. (Ranco)

REVERSING VALVE

A reversing valve changes the direction of refrigerant flow through a heat pump. See Fig. 28-3. The reversing valve is normally located inside the outdoor unit, immediately above the compressor. The valve body contains a slide valve and piston that is actuated (moved) by energizing or deenergizing a 24V solenoid coil. A group of three tubes is located on one side of the valve body and a single tube on the opposite side.

As shown in Fig. 28-4, the compressor discharges to the single tube. The middle tube on the *opposite* side of the reversing valve is connected to the compressor suction. (Refrigerant flow through the compressor is always the *same,* it does not reverse). The remaining two tubes on the reversing valve are connected to the indoor coil and outdoor coil.

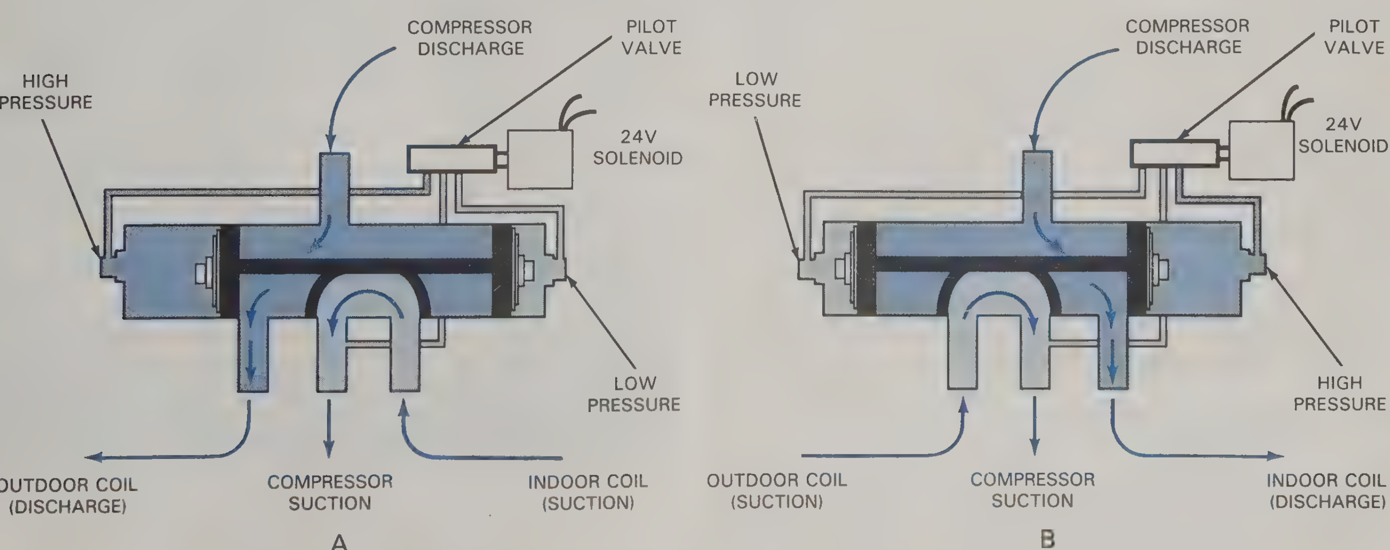


Fig. 28-4. Reversing valve operation. A–Cooling mode. B–Heating mode.

The position of the slide valve and piston inside the reversing valve determines the direction of refrigerant flow to and from each coil. Flow reversal is accomplished by the slide valve connecting one or the other of the outside tubes with the compressor suction tube of the valve. The valve position is controlled by energizing or deenergizing the solenoid coil.

The reversing valve is pilot-operated. The 24V solenoid coil and ***pilot valve*** serve to control the pressure difference at each end of the piston. There are three small tubes connected to the pilot valve body. Two of these tubes are connected to the ends of the reversing valve body. The center tube is connected to the suction line where it leaves the reversing valve body. The pilot valve automatically controls pressure (high or low) at each end of the piston. Energizing or deenergizing the solenoid coil causes pressure on the piston ends to reverse. Thus, system pressures are used to reverse piston position. Some heat pump systems energize the reversing valve during the cooling cycle, others during the heating cycle.

Fig. 28-5. A reciprocating-type compressor designed specifically for heat pump replacement applications. The compressor is equipped with a crankcase heater and is used with a suction accumulator like the one at left. (Tecumseh)

COMPRESSORS

The heat pump compressor operates as a high temperature machine during the cooling cycle, which is normal. During low ambients (heating cycle), the compressor operates as a low temperature machine with a steadily reducing capacity. The possibility of *liquid floodback* to the compressor during the heating cycle is very real. Compressors for heat pumps contain specially engineered features. Only compressors designated as "heat pump models" should be used for replacement. See Fig. 28-5.

Because liquid floodback is probable, all heat pumps are equipped with a suction accumulator to provide compressor protection. A crankcase heater is needed to protect against liquid migration (or condensation) during the off cycle.

The introduction of the ***compliant scroll compressor***, Fig. 28-6, has greatly improved compressor efficiency and reliability for heat pumps. It has become the compressor of choice for this application and is rapidly capturing the market. The compliant scroll feature permits the compressor to pump liquid without damage. This eliminates the need for installing a suction accumulator and crankcase heater to prevent liquid floodback. The scroll compressor also has fewer moving parts than the reciprocating type, thus greatly reducing lubrication problems.

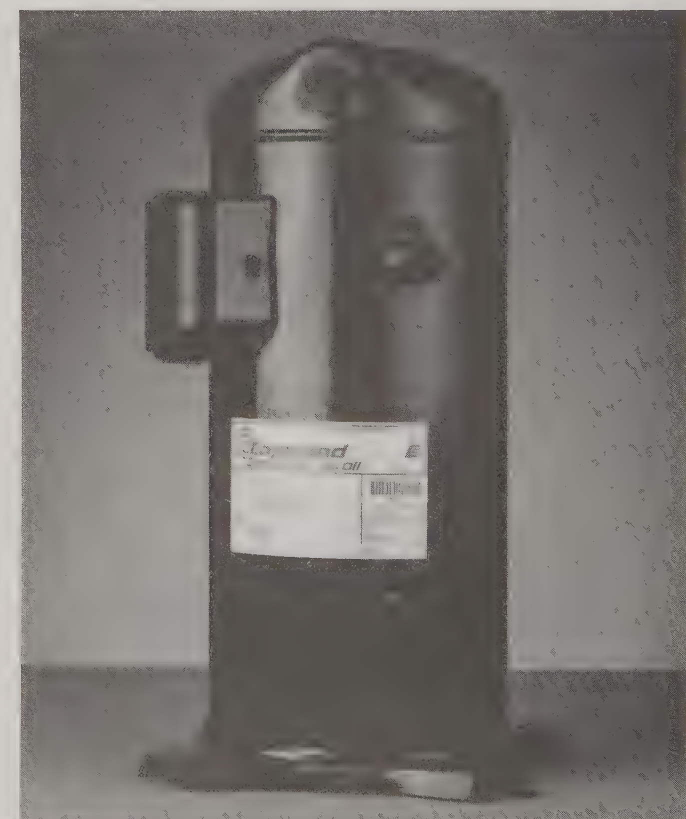


Fig. 28-6. The compliant scroll compressor design eliminates the need for a suction accumulator and a crankcase heater, since the scroll can pump liquid without damage. (Copeland)

REFRIGERANT METERING DEVICES

Proper control of liquid refrigerant entering the coils can be accomplished in several ways. These include thermostatic expansion valves with bypass lines, capillary tubes, and restrictor-type flow controls.

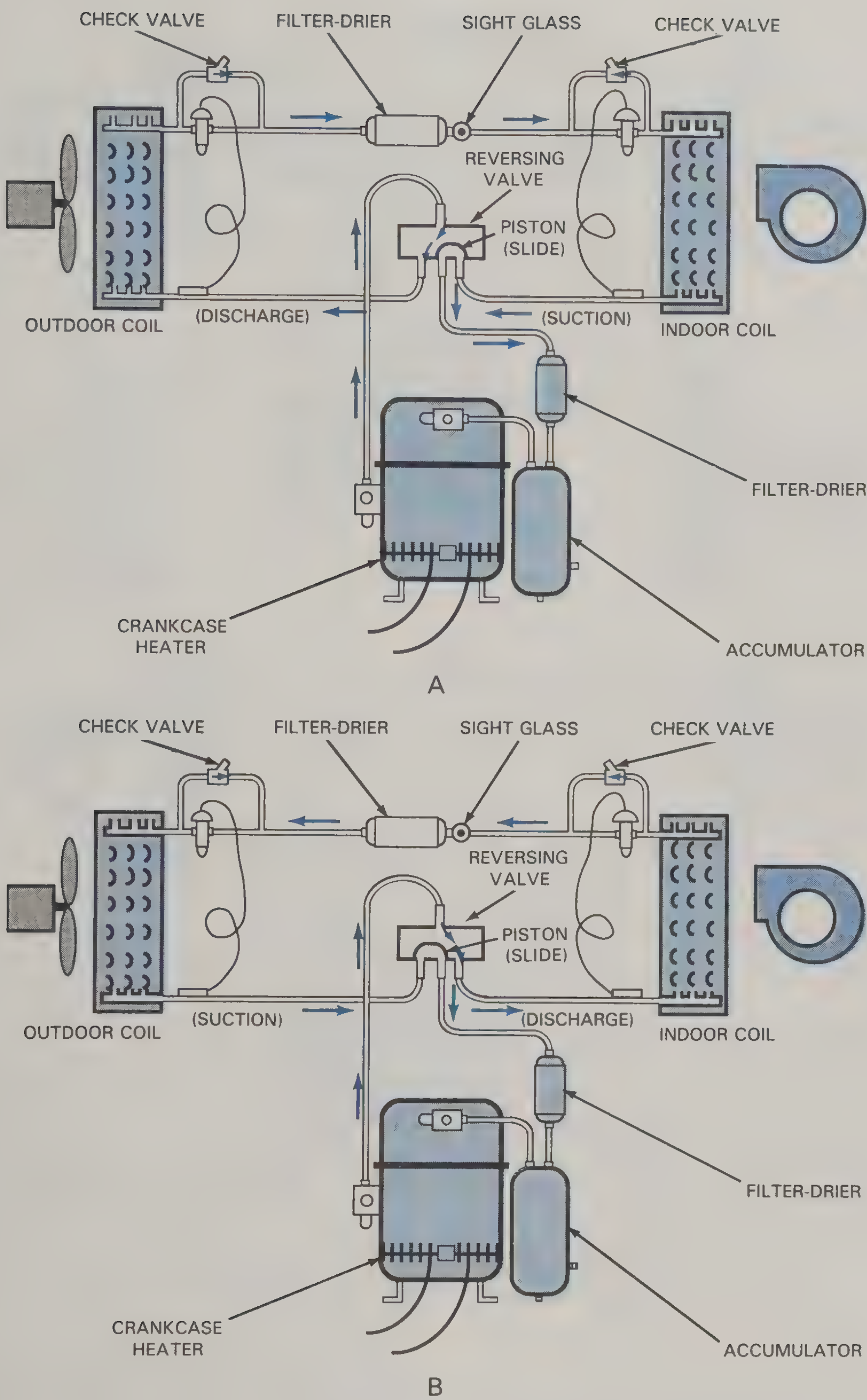


Fig. 28-7. A heat pump system using TEVs and bypass lines with check valves. Note the way that one check valve allows refrigerant to bypass the TEV in each mode.

Thermostatic expansion valves

Thermostatic expansion valves (TEVs) with bypass and check valves are popular on large heat pump systems. See Fig. 28-7. Because each coil must operate as an evaporator, a TEV is required on each coil. The expansion valve controls the amount of liquid entering the coil when it operates as an evaporator.

A *bypass line* is also needed for each coil. It permits refrigerant to bypass the expansion valve when the coil is operating as a condenser. A check valve is installed in the bypass line to control the direction of refrigerant flow in the bypass line.

Capillary tube

Metering devices for packaged or self-contained heat pumps normally consist of a capillary tube. Since a capillary tube operates equally well in either direction, bypass lines and check valves are not required. See Fig. 28-8.

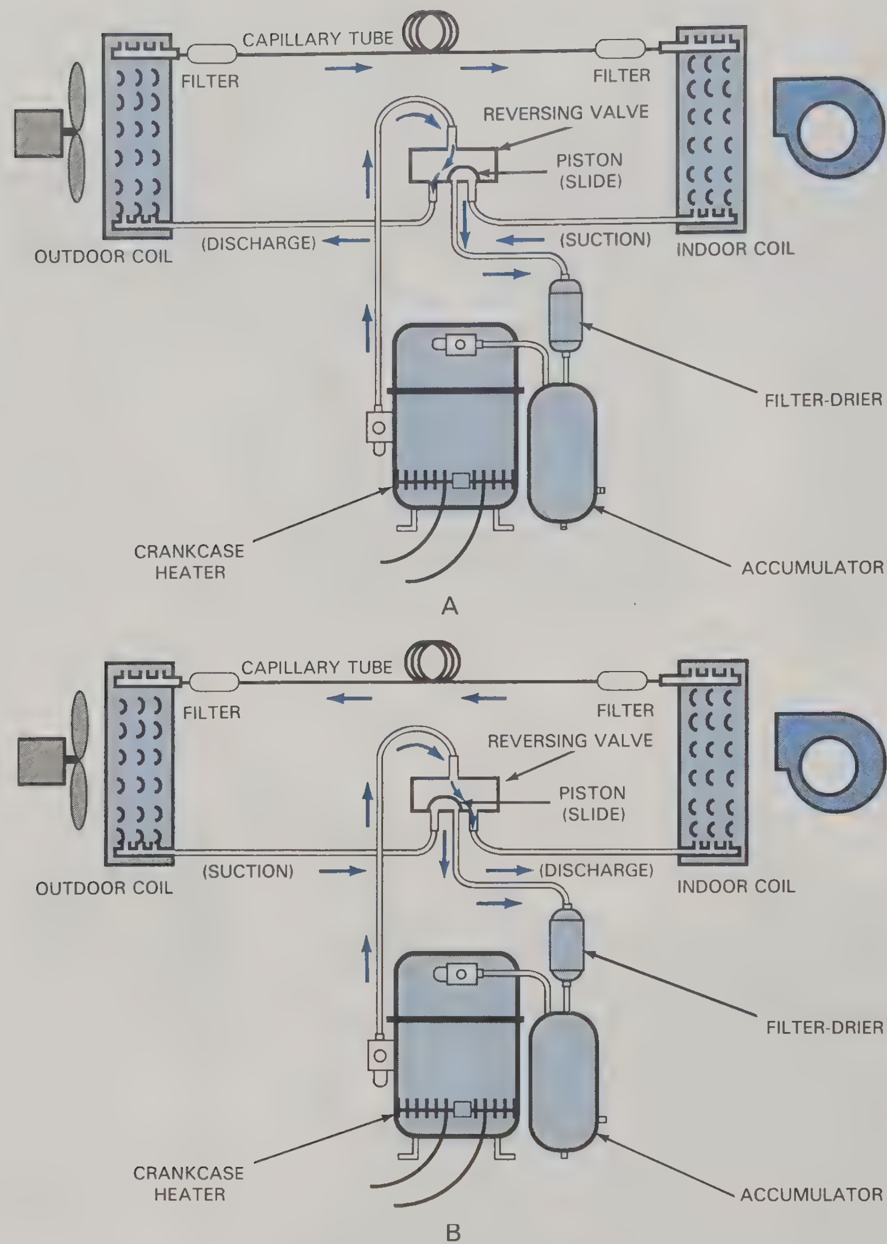


Fig. 28-8. A capillary tube system used to meter refrigerant in a heat pump. Check valves and bypasses are not needed.

Restrictor-type flow control

New technology has produced the restrictor-type flow control. This unique device replaces capillary tubes and thermostatic expansion valves. See Fig. 28-9.

In the cooling mode, the ***restrictor*** meters the flow of liquid refrigerant into the evaporator. The restrictor creates the necessary pressure drop to maintain the proper boiling point in the coil. Thus, the restrictor orifice acts much like a capillary tube. However, the restrictor is easily removed in the field and can be replaced with one of a different orifice size. This would provide a different flow rate and corresponding pressure drop.

When in the heating mode, this flow control device allows unrestricted reverse flow. As liquid refrigerant flows in reverse direction, the restrictor automatically moves to the free flow position. This reverse flow capability eliminates the need for a check valve and bypass tubing.

On a heat pump, the indoor and outdoor coils are physically different in size and capacity. To compensate for the pressure difference this creates, a restrictor of a different size is used for each coil. During the heating cycle, the outdoor coil becomes the evaporator and requires more restriction.

AIRFLOW STANDARDS

The Air Conditioning and Refrigeration Institute (ARI) is the accepted authority for establishing industry standards. The airflow standard for regular air con-

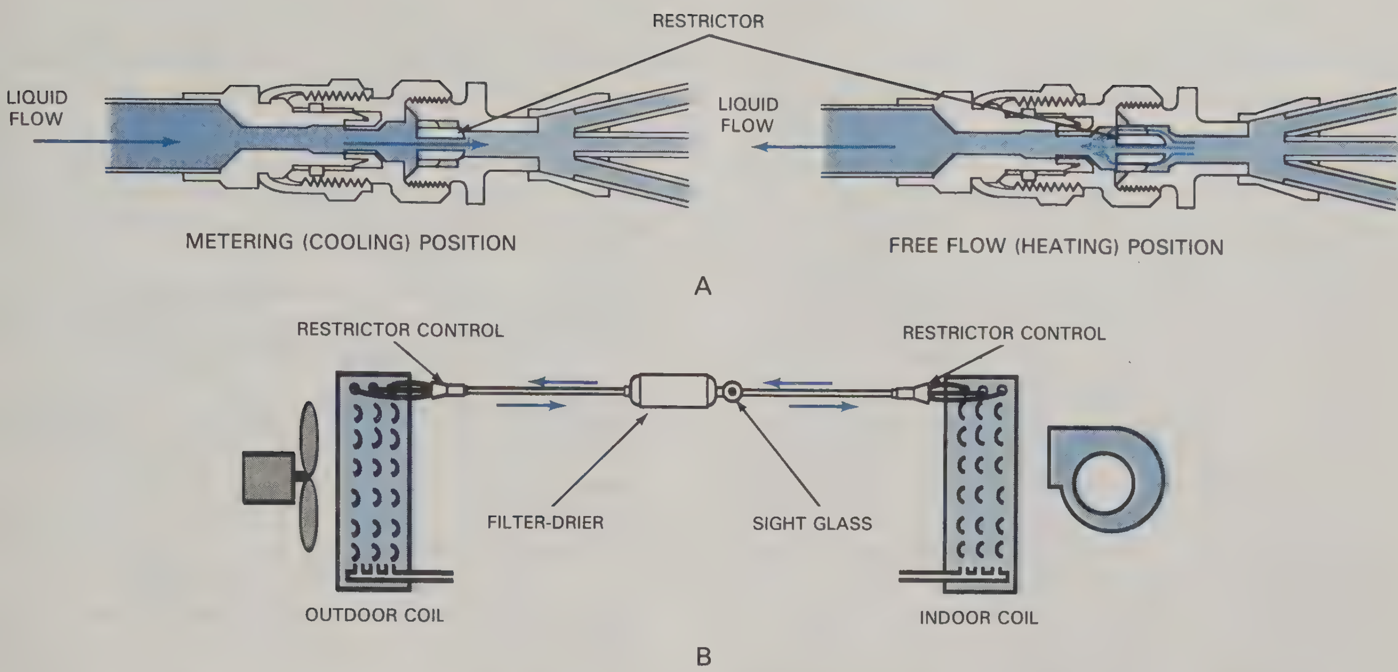


Fig. 28-9. Restrictor-type flow control. A–As shown in the cutaway views, the restrictor precisely meters refrigerant during the cooling mode, but allows unrestricted reverse flow in the heating mode. (Aeroquip) B–One control is needed at each coil. The need for expansion and check valves, bypasses, or capillary tubes is eliminated.

ditioning is 400 cubic feet per minute (cfm) per ton over the evaporator, and 700 cfm/ton over the condenser.

Since a heat pump is reversible, however, the airflow through each coil must be the same. This standard has been set at 450 cfm/ton. This is a greater air volume over the indoor coil than for regular air conditioning systems, and less air volume over the outdoor coil. When adding a heat pump to an existing furnace, or making a conversion replacement, the existing duct system may be undersized.

During the heating cycle, the temperature rise over the indoor coil is considerably less than a conventional furnace. Supply air temperature to the room would be about 105°F (41°C) when outdoor temperature is 30°F. This provides a temperature rise of about 35°F (19°C) over the coil, compared to about 60°F (33°C) for a gas or oil furnace. The air will seem to be cooler, due to increased volume. This does not affect the system's ability to maintain desired room temperature–it simply runs longer to satisfy the thermostat.

The outdoor coil receives much less air than is normal for a regular air conditioning system. Heat rejection during the cooling cycle is less efficient. During the heating cycle, slower airflow permits better heat pickup. Some manufacturers use a two- speed motor on the outside coil to deliver more air during the cooling cycle. This lowers the head pressure and permits more efficient operation.

DEFROST CYCLE

Heat pumps require the use of a *defrost cycle* to remove frost from the outdoor coil. The outdoor coil becomes an evaporator during the heating cycle, and is about 10°F (6°C) colder than the ambient air. Whenever the coil temperature is below 32°F (0°C), frost and ice will accumulate on the outdoor coil, Fig. 28-10. This buildup of frost must be removed periodically to maintain proper airflow.

The most practical way to remove ice buildup is to heat the coil. For a defrost cycle, the system is automatically switched to the cooling mode, even though the thermostat calls for heating. This converts the outdoor coil into a condenser. Frost is quickly melted because the outdoor fan motor is turned off during defrost.

Heat is removed from the interior of the building during a defrost cycle. To solve this problem, electric

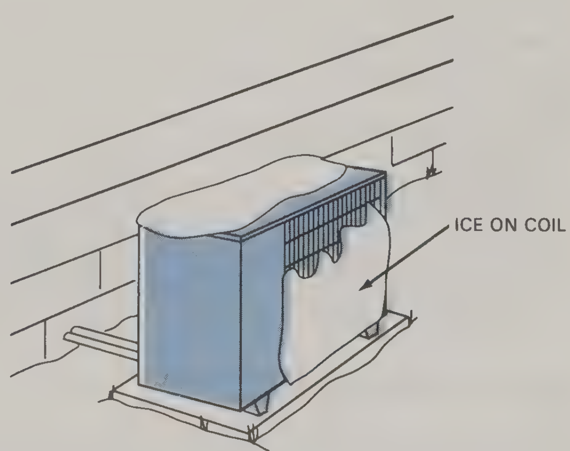


Fig. 28-10. A defrost cycle is needed to remove frost on the outdoor coil of a heat pump.

resistance heat is turned on during defrost so air delivered to the building interior will be warm.

There are several ways to control the defrost cycle. A pressure differential switch could be used to sense increased pressure drop across the coil as frost forms. A temperature switch could be used to sense the decrease in coil temperature as frost forms. The most common method is the time-initiated/temperature-terminated defrost. This system has a defrost timer that runs whenever the compressor is operating. About every 90 minutes, the timer mechanically closes a switch to energize the defrost relay and initiate a defrost cycle.

A special thermostat is used to sense outdoor coil temperature. The thermostat's contacts open on rise (65°F or 18°C) and close on fall (32°F or 0°C). The thermostat contacts are connected in series with the timer switch and defrost relay. The thermostat's contacts close when coil temperature drops to about 32°F (0°C). To initiate a defrost cycle, two conditions must be met: the timer must have completed its 90 minute cycle *and* the coil temperature must be 32°F. If one of these elements is lacking, no defrost occurs. The system waits another 90 minutes to try again.

The defrost cycle is terminated by the thermostat when coil temperature rises to 65°F (18°C). The defrost cycle may require 5 to 6 minutes when frost accumulation is heavy. This occurs when outdoor ambient is about 40°F (4°C). At lower ambients, outdoor air contains less humidity and the defrost cycle may terminate in three minutes. If thermostat fails to do so, the clock will terminate the defrost cycle after 10 minutes.

NOTE: A large vapor cloud may appear at the outdoor unit during defrost. This is normal and indicates the defrost cycle is operating properly.

CHARGING A HEAT PUMP SYSTEM

The amount of refrigerant in a heat pump is critical for efficient operation. The most accurate and efficient method of charging the system is by weight. The proper refrigerant type and the amount (pounds and ounces) is normally indicated on the unit data plate. Charging by exact weight can be performed year-round, in either the heating or cooling mode.

HEAT PUMP FILTER-DRIERS

Most filter-driers are direction-sensitive and must be installed according to refrigerant flow. These filter-driers cannot be used on heat pumps, due to reversing refrigerant flow. Special filter-driers that permit reverse flow are available for heat pumps.

HEAT PUMP THERMOSTATS

Two types of thermostats are used to operate heat pumps. One type is the two-bulb thermostat with manual changeover from heating to cooling. The other type is four-bulb thermostat with automatic changeover. Thermostats used on heat pumps are split-subbase thermostats, which may include a variety of special features, such as:

- Isolating contacts that allow the use of two separate 24V transformers. The jumper between terminals V and VR at the subbase must be removed to isolate the circuits.
- Emergency heat switch for energizing auxiliary heat during a heat pump shutdown. A small amber light on the thermostat indicates when emergency heat is energized.
- Service light (red) that indicates when heat pump malfunctions during the heating cycle and auxiliary heaters are providing all the heat.

The various terminals that may be found on the heat pump thermostat subbase include:

V = voltage from heat pump transformer
VR = voltage from indoor unit transformer
F = indoor fan
M = compressor
R = reversing valve
Y = auxiliary heat
E = emergency heat

The two-bulb thermostat with manual changeover is found today only on older heat pumps. With this thermostat, the reversing valve is automatically energized when the manual system switch is moved to the cooling position. See Fig. 28-11. The first bulb (which has two mercury switches) is used to start the compressor for heating or cooling. The second bulb controls auxiliary heat. An outdoor thermostat is normally connected in series with the auxiliary heat to prevent energizing auxiliary heat unless outdoor temperature is low enough to require it.

A four-bulb thermostat, Fig. 28-12, uses the first-stage cooling bulb to energize the reversing valve. The second-stage cooling bulb controls the compressor. During the heating cycle, the reversing valve is not energized and the first-stage heating bulb controls the compressor.

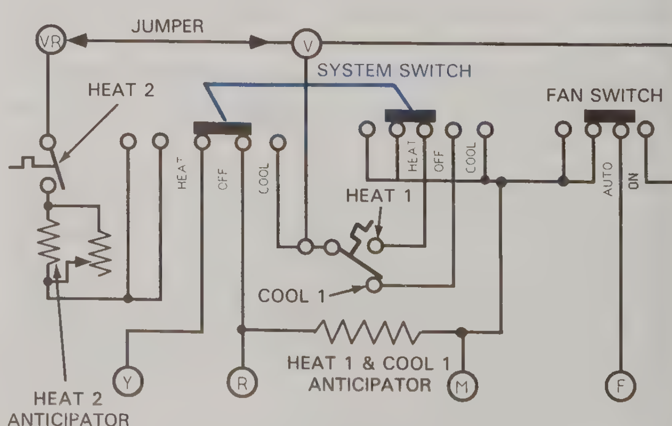


Fig. 28-11. Schematic of a two-bulb thermostat for use with a heat pump. The second bulb ("HEAT 2") controls auxiliary heat. Changeover from heating to cooling, and vice versa, is done with a manual switch.

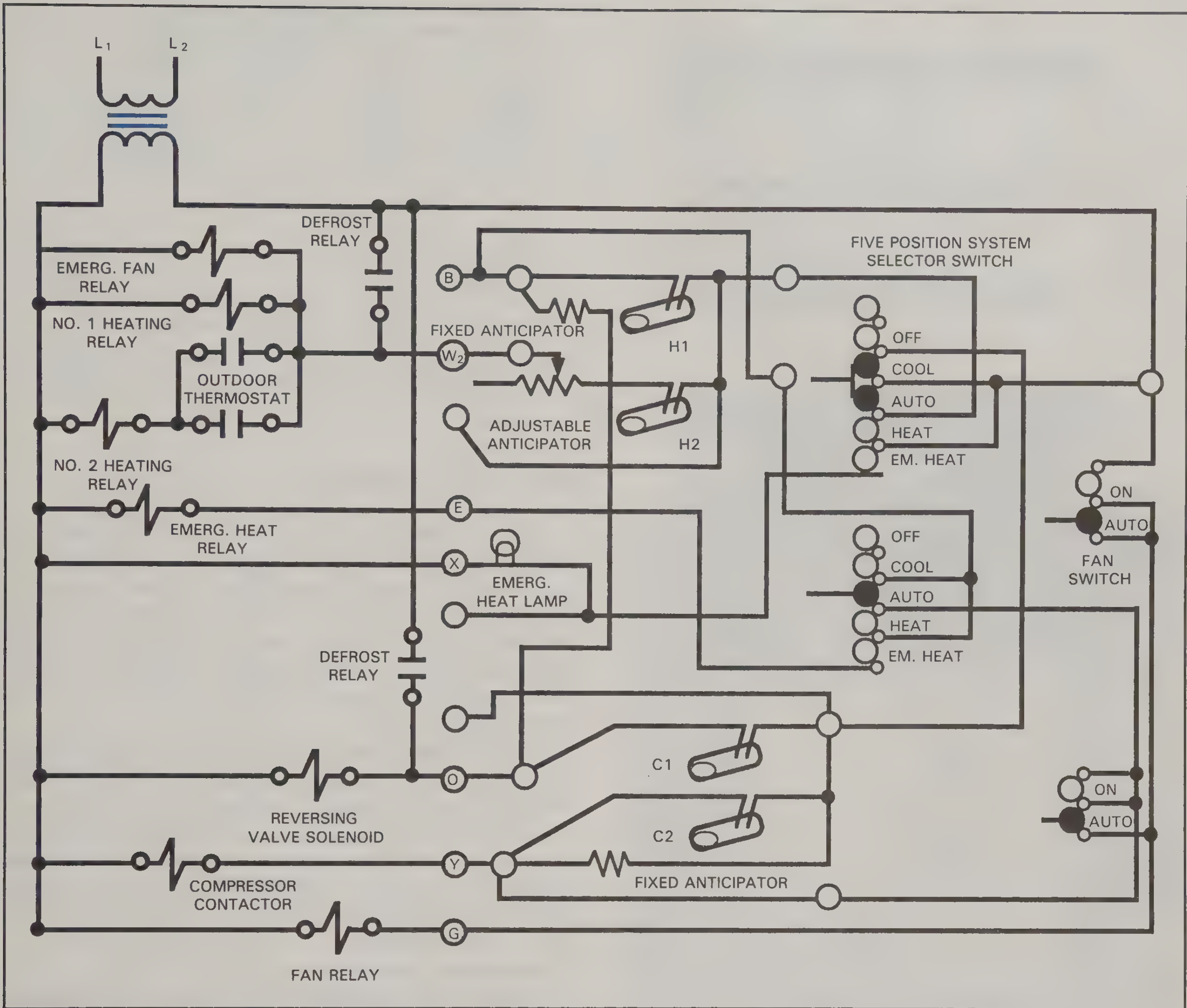


Fig. 28-12. A schematic of a four-bulb thermostat for use with a heat pump. Two bulbs are used for each mode.

The second-stage heating bulb controls auxiliary heat. Therefore, the four-bulb thermostat energizes the reversing valve during the cooling cycle.

The four-bulb thermostat may include a manual ***emergency heat switch*** to energize auxiliary heat. A small indicator light is located on the thermostat as a reminder that emergency heat is being used. Another feature is the system auto switch for automatic changeover from heating to cooling by the thermostat. These features require a special subbase. See Fig. 28-13.

Outdoor thermostat

An ***outdoor thermostat*** is normally used to prevent energizing auxiliary heat stages until outdoor temperature is low enough to require supplemental heat. See Fig. 28-13. The outdoor thermostat is connected in series with the indoor thermostat's second-stage heating bulb. This ensures that the auxiliary heat cannot be energized unless *both* indoor and outdoor thermostat contacts are closed.

Low-ambient thermostat

Another control found on a heat pump is a ***low-ambient thermostat***. Heat pump efficiency is greatly reduced when outdoor temperature drops to the range of 10°F to 15°F (-12°C to -9°C). The low-ambient thermostat is located in the outdoor unit, with the contacts connected in series with the compressor contactor coil. This control prevents the compressor from operating during periods of very low outdoor temperatures.

READING HEAT PUMP SCHEMATICS

Electrical circuits for controlling heat pumps will vary greatly from model to model and from one manufacturer to another. The electrical control circuits can

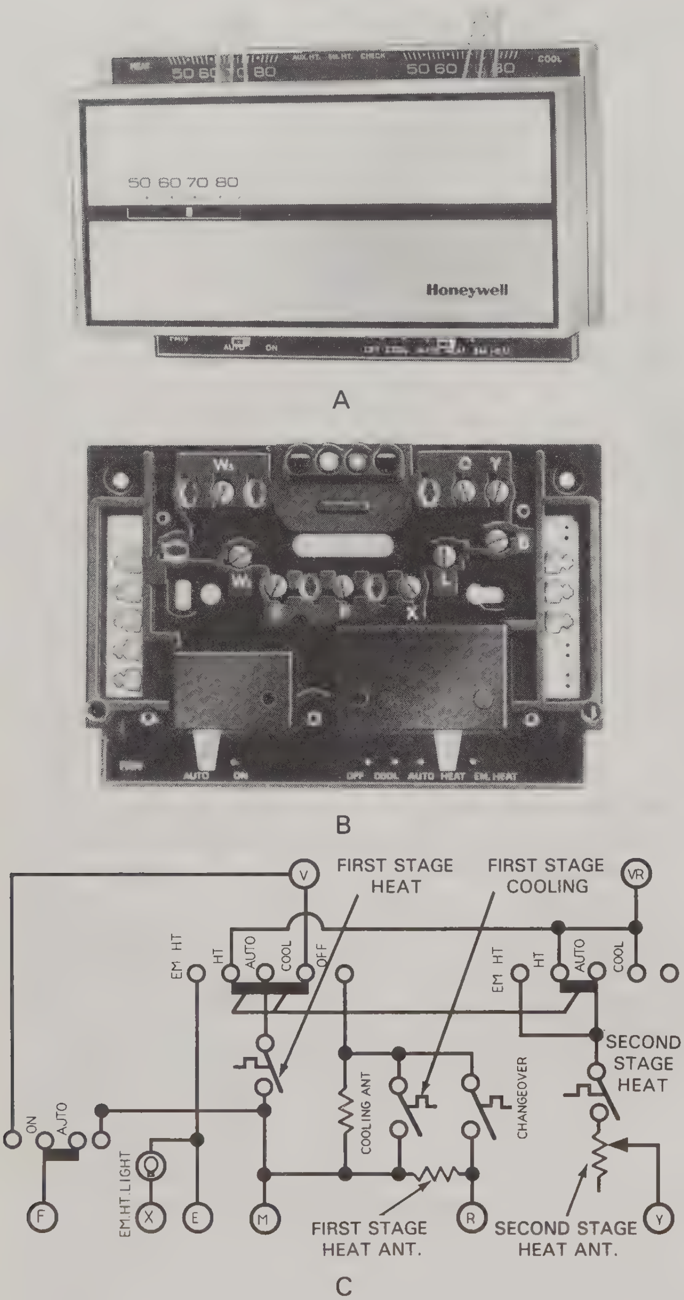


Fig. 28-13. Four-bulb thermostat for use with heat pump. A–Thermostat features automatic heating/cooling change-over, but can be manually switched as well. (Honeywell) B–Subbase contains necessary terminals and contacts for automatic and manual functions. (Honeywell) C–Schematic of thermostat.

vary from simple to complex. Most heat pump schematics are complex, since they may include a defrost cycle, safety controls, and accessory features.

The heat pump service technician must be knowledgeable in heat pump theory and be able to read schematics. The manufacturer's schematics of each unit explains how the electrical components are connected. Understanding the purpose of these controls and circuits provides the information needed for troubleshooting.

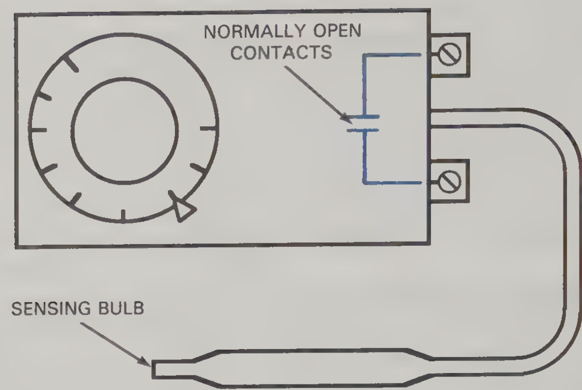


Fig. 28-14. The outdoor thermostat prevents energizing of auxiliary heat circuits until the selected outdoor temperature is reached.

HEAT PUMP CIRCUITS

The following step-by-step electrical schematics are used to illustrate the general operating principles of heat pumps. Some of the electrical circuits shown are common to many systems, while the control concepts are realistic. Many variations are possible in types of components and control circuits. Always check each unit's wiring schematic and pictorial for methods and sequences of operation.

The schematic shown in Fig. 28-15 begins with basic connections for a heat pump system. This schematic includes the compressor, outdoor fan, transformer, thermostat, auxiliary heat relay, reversing valve, compressor contactor, and indoor blower relay. Additional controls will be added to this schematic step-by-step in following illustrations.

Outdoor fan and defrost relay

The ***outdoor fan and defrost relay*** combines two relays into one component. See Fig. 28-16. Several switches are controlled by the relay coil. The relay coil can be either 24V or 24OV, depending on the type of defrost control circuit. When a defrost cycle is initiated, the relay coil is energized and causes three actions:

- An NC contact will open and turn off the outdoor fan. Defrost is easier and quicker if cold air is not blowing over the outdoor coil.
- An NO contact will close, energizing the reversing valve coil. This switches the system to the cooling cycle. Hot gas is pumped to the outdoor coil.
- Another NO contact closes, completing a 24V circuit to the auxiliary heat relay. The auxiliary heat is needed to offset the cooling effect of the indoor coil. Refer to Fig. 28-17.

Types of defrost controls

There are several types of defrost controls in common use: timeclock, solid state defrost control, mechanical switch, and air differential switch. Each accomplishes the same purpose, but in a different man-

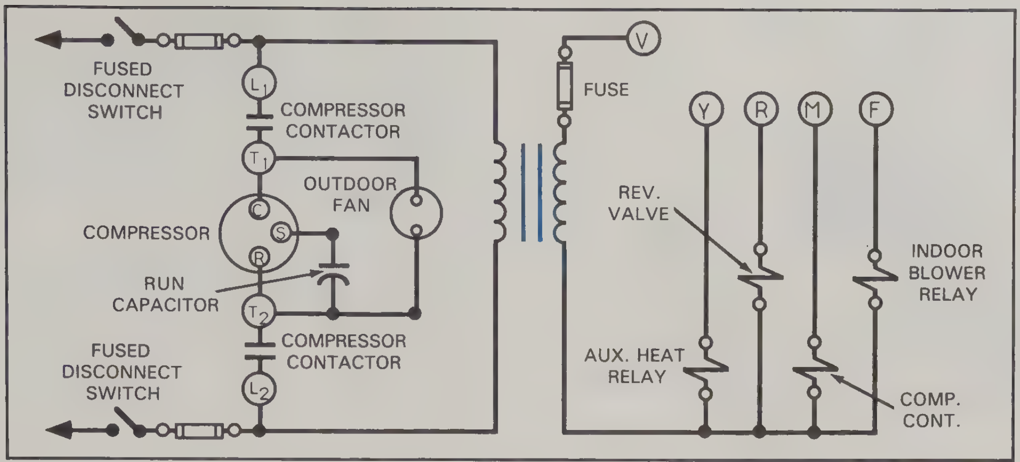


Fig. 28-15. Basic schematic for a heat pump.

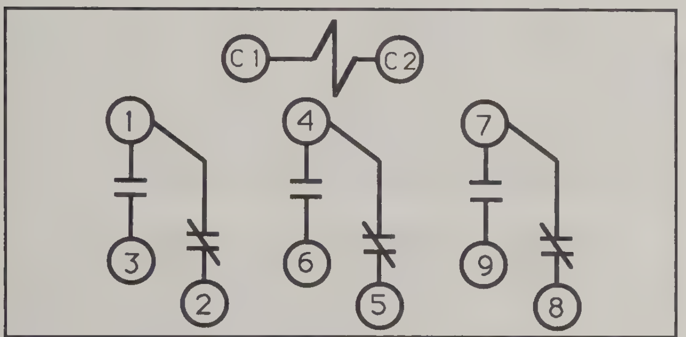


Fig. 28-16. Schematic of the combination outdoor fan and defrost relay.

ner. The method illustrated here uses a defrost timeclock in combination with a defrost thermostat.

Defrost timeclock. The defrost timeclock motor operates on 208V to 24OV. A rotating cam controls the mechanical opening and closing of two switches. See Fig. 28-18. The timer motor is connected in parallel with the outdoor fan motor and runs whenever the compressor contactor is energized. Every 90 minutes, the timer closes the normally open set of contacts that are

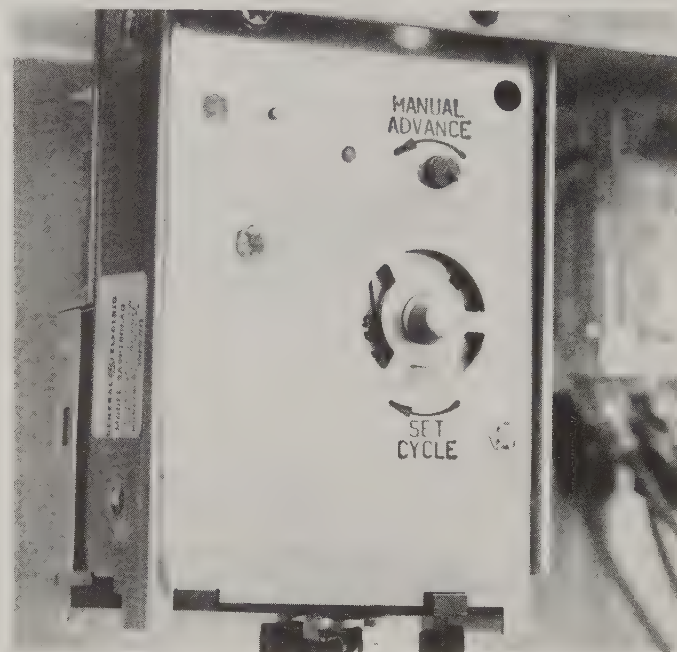


Fig. 28-18. A typical defrost timeclock. A rotating cam controls mechanical switches to start and stop the defrost cycle. (Lennox Industries, Inc.)

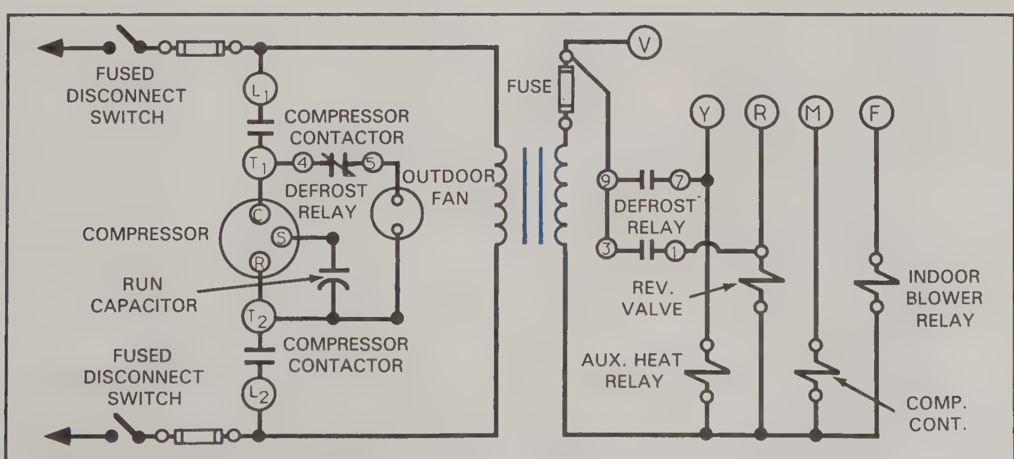
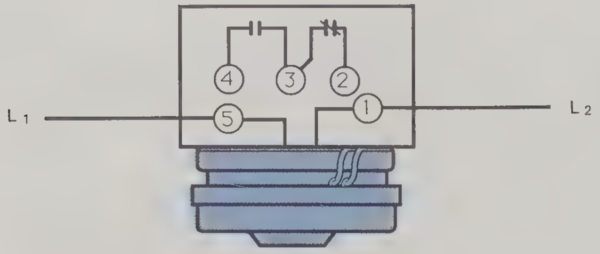


Fig. 28-17. Basic schematic with outdoor fan and defrost relay added.



TERMINALS 1 AND 5 ARE LINE VOLTAGE

Fig. 28-19. To begin the defrost cycle, the timer closes the NO switch between terminals 3 and 4 every 90 minutes. If the outdoor coil temperature is at or below 32 °F, the defrost cycle will begin.

located between terminals 3 and 4. Refer to Fig. 28-19. The outdoor thermostat contacts are connected in series with power supply to clock terminal 4. The outdoor thermostat contacts do not close unless the outdoor coil temperature is at or below 32°F (0°C). A circuit to the defrost relay cannot occur unless *both* timeclock and outdoor thermostat contacts are closed, Fig. 28-20.

The defrost cycle is normally terminated by the outdoor thermostat when the outdoor coil temperature reaches 65°F (18°C). If the defrost timer switch closes and the thermostat contacts are open, a defrost is not needed and cannot occur. The timer then proceeds through another 90 minute cycle. During a defrost cycle, the timer motor is deenergized along with the outdoor fan motor. This is controlled by the defrost relay.

Crankcase heater

The crankcase heater is energized at all times, and is connected to the line side of the compressor contactor. The crankcase heater helps prevent possible compressor damage resulting from liquid slugging. Slugging normally occurs at startup. See Fig. 28-21.

Low-ambient thermostat

The low-ambient thermostat contacts are connected in series with terminal M on the indoor thermostat and the compressor contactor coil. This control prevents the compressor from operating when outdoor temperature reaches 10°F to 15°F (-12°C to -9°C).

High- and low-pressure controls

Both high- and low-pressure safety controls are connected in the 24V circuit. Their contacts are connected in series with terminal M on the indoor thermostat, which controls power supply to the compressor contactor coil.

TYPICAL HEAT PUMP SCHEMATIC

Fig. 28-22 is a schematic of a typical heat pump system. This schematic shows the outdoor unit, indoor blower unit, auxiliary electric heat, and the control circuits. Separate power supplies (each with disconnect and fuses) are required for the outdoor unit and the indoor unit.

TROUBLESHOOTING HEAT PUMPS

As described in Chapters 25-27, systematic troubleshooting of heating and cooling systems requires skills that must be cultivated and developed. A service call tests the technician's knowledge, mechanical skills, and ability to observe and interpret information. Good troubleshooting require the use of information to make a conclusion. Hasty decisions, or wrong information, results in wrong conclusions. Troubleshooting involves using step-by-step procedures and a *process of elimination* to pinpoint the problem. There are five important steps involved in systematic troubleshooting:

1. Know what the equipment *should do.*
2. Know what the equipment is *doing.*

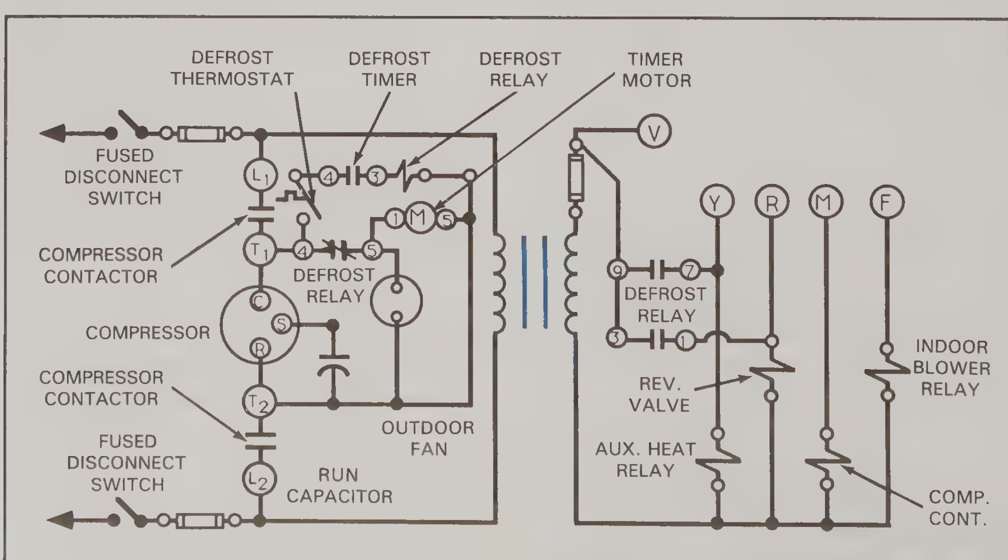


Fig. 28-20. Schematic with the defrost timer added. Both the timer contacts and the outdoor (defrost) thermostat contacts must be closed to begin the defrost cycle.

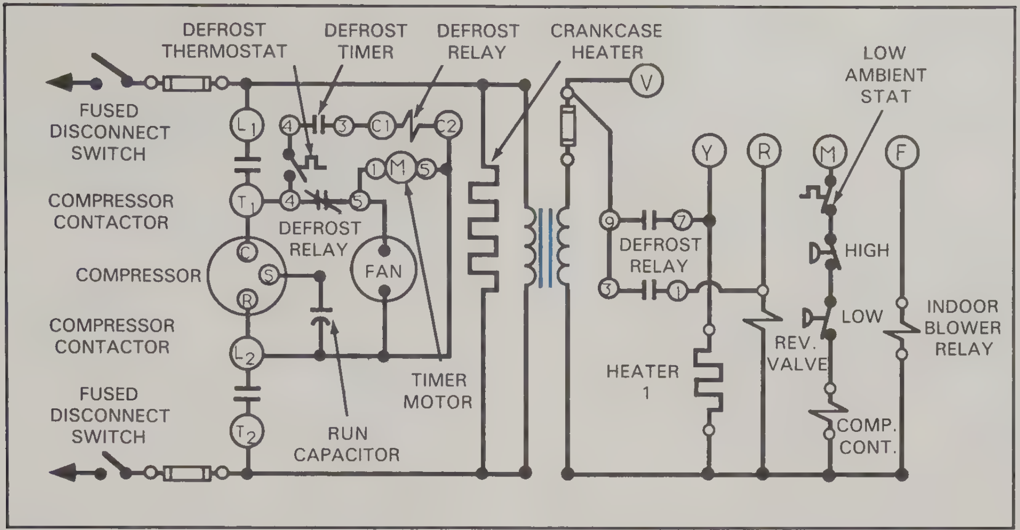


Fig. 28-21. The crankcase heater, low ambient thermostat, and high- and low-pressure safety controls have been added to the heat pump schematic.

3. Know what the equipment is *not* doing.
4. Eliminate areas that *are* functioning properly.
5. Concentrate on areas that are *not* functioning properly.

The customer's complaint usually helps narrow the problem to a specific area. These complaints fall into one of six possible headings:

- No heat or no cooling.
- Not enough heat.
- Too much heat.
- Noise.
- Odor.
- Excessive operating cost.

A question or two to the homeowner, plus a few observations of the equipment, should aid in the process of elimination. By listening, observing, and testing, the technician discovers clues that point to the exact problem. Some of the most likely causes are listed under each problem area.

NO HEAT

- Wrong thermostat settings.
- Broken or loose thermostat wires.
- Defective thermostat.
- No power supply (check fuses, circuit breakers).

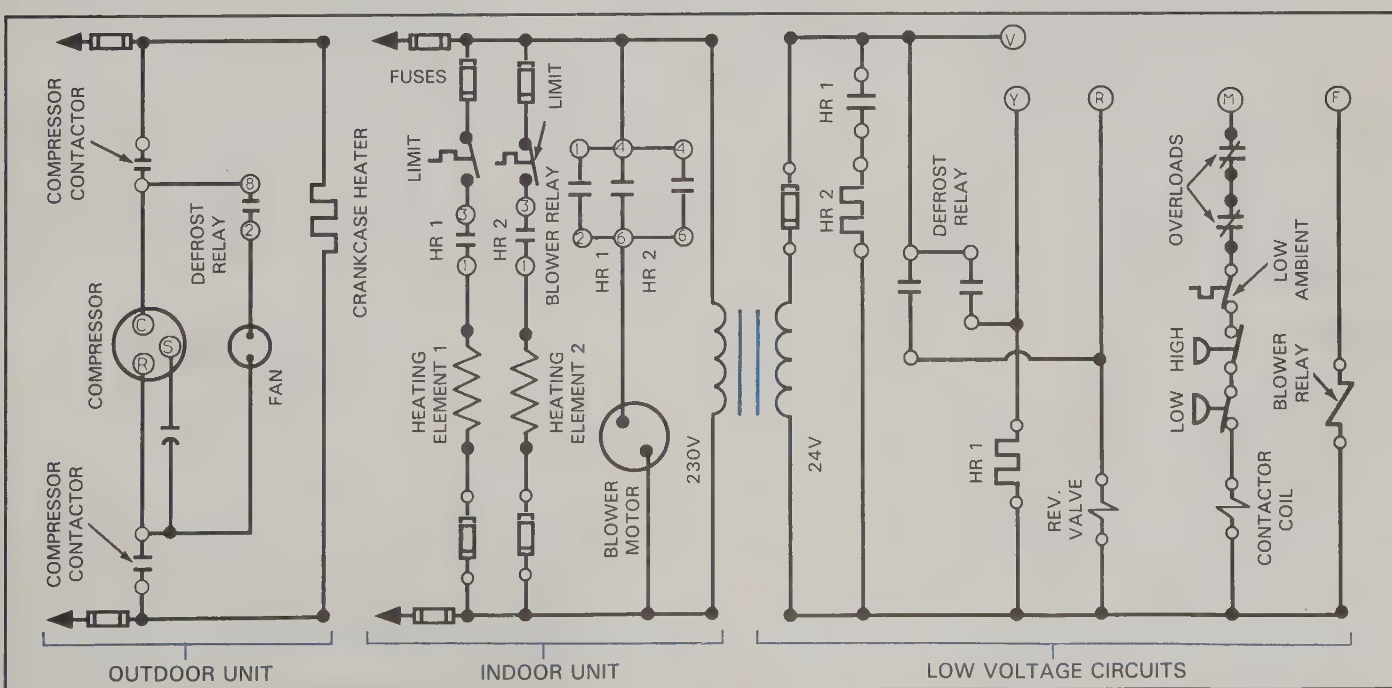


Fig. 28-22. A typical schematic for a complete heat pump system.

- Low voltage at transformer secondary (less than 22V).
- Low voltage at transformer primary (more than 10 percent drop).
- Defective transformer (check fuse).

NO COOLING

- Low voltage transformer problem.
- Faulty thermostat or subbase.
- Wrong thermostat settings.
- Defective low-ambient thermostat.
- Defective compressor contactor.
- Defective compressor.
- Low pressure safety switch open.
- High pressure safety switch open.
- Defective compressor start components (capacitors and relay).
- Defective reversing valve or coil.

NOT ENOUGH HEAT

- Wrong thermostat settings.
- Wrong heat anticipator adjustment.
- Vibration at thermostat.
- Thermostat influenced by warm air.
- Defective thermostat.
- Wrong setting on outdoor thermostat.
- Wrong location of outdoor thermostat.
- Defective outdoor thermostat.
- Dirty or clogged air filter.
- Blower motor problem.
- Defective high limit control.
- Defective heat relays.
- Defective heating elements.

TOO MUCH HEAT

- Thermostat not level.
- Heat anticipator set too high.
- Thermostat in cold draft.
- Defective thermostat.
- Defective heat relay.
- Control circuit "shorted."
- Compressor contactor welded shut.

NOISE

- Loose blower bearings.
- Blower bearing dry and squeaking.
- Blower wheel off-center.
- Loose V-belt.
- Loose running gear and mounts.
- Filter caught in running gear.
- Loose cabinet panels.
- Loose relay mountings.
- Noisy contactor (replace).
- Humming transformer (replace).
- Loose duct work.

ODOR

- Dirty air filters.
- Stagnant water or sludge in humidifier.
- Control transformer burning out.
- Overheated wiring or overloaded circuit.
- Relay shorted or burned.
- Dirty heating elements.

EXCESSIVE COST OF OPERATION

- Thermostat problems.
- Outdoor thermostat problem.
- Defective heating relay.
- Dirty air filter.
- Insufficient home insulation.
- Excessive air leakage from home (fireplace, vents, etc.).
- Defective blower motor with high amperage.
- Blower belt too tight.
- Dirty blower wheel.
- Wrong humidity.
- Unit cycling on low-pressure safety switch.
- Unit cycling on high pressure safety switch.
- Defective compressor valve reeds.
- Reversing valve stuck or leaking.
- Defective defrost cycle.

SUMMARY

This chapter introduced the theory and operation of residential heat pumps. The design and application of air-to-air heat pumps in residential installations was described in a step-by-step manner. Control and operation of the system was explained by giving each component individual attention. Some variations in individual components were discussed. The limitations (balance point) of heat pumps and the need for auxiliary heat was covered, as well.

Thermostats, relays, and timers are used for automatic control of heat pump operation. These complex circuits, along with safety controls, were explained and illustrated by using simple step-by-step electrical schematics. A troubleshooting guide and a complete electrical schematic of a typical residential heat pump system concluded the chapter.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. What component of the heat pump controls direction of refrigerant flow?
2. Which term is used to describe the intersection on a graph of lines that represent the heat pump's capacity and the building's heat loss?
   a. Coefficient of performance.
   b. Balance point.
   c. Energy efficiency ratio.
   d. Pressure regulation threshold.

3. Flow reversal is controlled by energizing or deenergizing the ________ of the reversing valve.
4. What type of compressor is best for heat pumps?
5. Name three types of refrigerant metering devices used on heat pumps.
6. Heat pumps require a defrost cycle to remove frost from the ________ coil.
7. For a defrost cycle, the system automatically switches to the ________ mode.
8. True or false? Frost cannot form on the outdoor coil when the coil temperature is below 32°F (0°C).
9. What device terminates the defrost cycle?
10. At what temperature does the defrost termination thermostat open?
11. What is the most efficient method of charging a heat pump?
12. What type of heat pump indoor thermostat is most commonly used today?
13. The outdoor thermostat is used to help control ________.
14. What device is used to prevent compressor operation when the outdoor temperature is below 10°F to 15°F (-12°C to -9°C)?
15. Which terminal on the indoor thermostat controls the reversing valve?

In a heat pump, the direction of the refrigerant flow is controlled by a four-way reversing valve. To accommodate the range of heat pump capacities needed for various applications, reversing valves are available in a range of sizes. (Ranco)

The product sold by a technician is service. If you provide that service promptly, efficiently, and correctly, the customer will be satisfied and is likely to direct any future business to your company. (Lennox International, Inc.)

Chapter 29

CUSTOMER RELATIONS

After studying this chapter, you will be able to:
- *Discuss how to win arguments by avoiding them.*
- *Tell why it is important to learn and use people's names.*
- *Describe how to shake hands properly.*
- *Discuss the importance of good appearance.*
- *List ways of showing respect for others.*
- *Develop the skill needed to deal effectively with angry customers.*
- *Discuss the value of admitting when you are wrong.*
- *Demonstrate how to begin and end service calls properly.*

NEW WORDS

callback	first impression
criticism	people skills
customer relations	win-win situation

PEOPLE SKILLS

This chapter is intended to help you solve the problem of dealing with customers and others. To be successful in a service business requires special training in ***people skills,*** the fine art of working well with people. The service technician must be able to think quickly and follow the rules for working with people effectively. Good mechanical skills combined with good people skills provides the quickest road to success, Fig. 29-1.

Many people assume they have good people skills, but fail miserably when involved in actual ***customer***

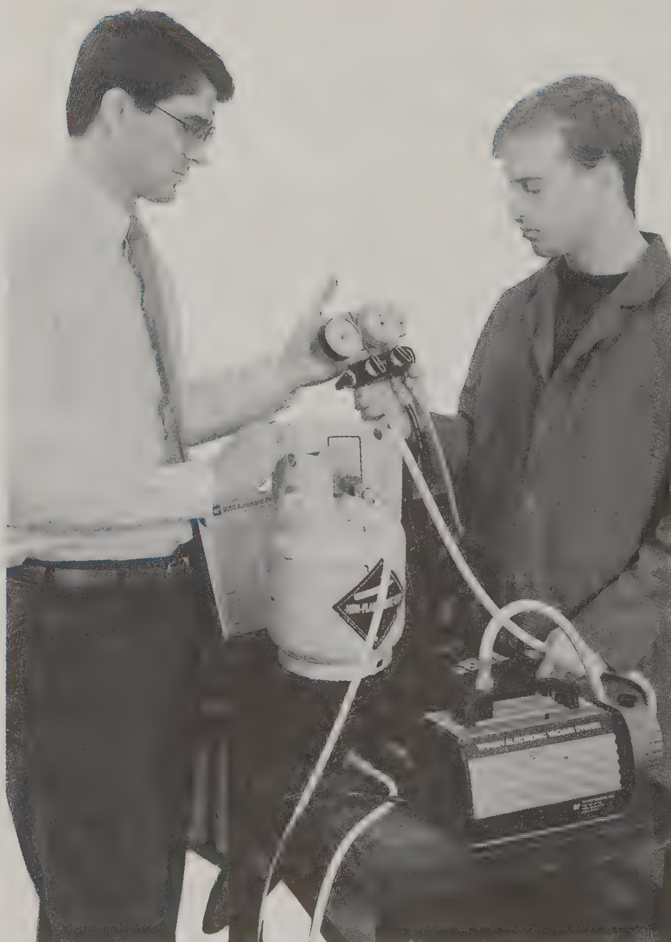


Fig. 29-1. In school or in training classes, learning how to work with people is just as important as learning how to use equipment and work with heating, cooling, or refrigeration systems. Good ''people skills'' will be beneficial whether you are a technician employed by a company, or operate your own business. (Ferris State University)

relations. You probably have been treated in a rude manner by people in a number of business situations. Most likely, you became angry–as a paying customer, you deserve, expect, and demand better treatment. It's a fact of economic life that angry or disappointed customers take their business elsewhere.

Your customers and fellow workers have problems just like everyone else and they sometimes become upset. Special skills are required to handle these situations and maintain good relations. These skills result in respect and a favorable attitude toward you: people respond positively to someone they like.

Some experts estimate that, for a person in his or her own business, about 15 percent of financial success is due to technical skill and 85 percent to skill in working with people. Employers are eager to hire women and men who have good leadership and people skills. These special skills are easy to learn, but you must put forth some effort and practice to master them and make them a "habit." This chapter provides the necessary information and guidelines. You must apply the guidelines in everyday life to make these new skills work for you. This requires time, persistence, and daily application.

THE FIRST RULE

The first rule of people skills is to *never* criticize or find fault.

People hate to be criticized and usually refuse to accept the criticism. Being critical, even in jest, is a quick way to start an argument or make an enemy. ***Criticism*** is dangerous because it hurts a person's pride and destroys their concept of self-importance. People become defensive when criticized. They will defend their actions and condemn *you*. Criticism causes bad feelings and severely impairs all further conversation.

Regardless of what a person does, it makes perfectly good sense to them *at the time*. You may not agree with their logic, but it does make sense *to them*. People will argue and defend their reasoning because they do not want to appear stupid. Even if criticism appears justified, restrain yourself. Who knows, under similar circumstances you might have acted in the same manner.

Always keep an open mind and don't find fault. Nobody likes a complaining grouch. Too often, people are quick to criticize and rarely give a sincere compliment or "pat on the back." *Sincere* compliments are always welcome and appreciated. People respond favorably to them, but easily recognize insincere *flattery*. Some people will readily accept flattery, but most will react negatively to it.

When dealing with people, you are not necessarily going to get responses based on logic. Most often, you are dealing with emotions, prejudices, pride, and vanity. Any fool can criticize and find fault, which can lead to disaster. It takes character and self-control to be understanding and forgiving, which leads to success.

HOW TO WIN AN ARGUMENT

The only way to win an argument is to *avoid* it. Never permit yourself to become a participant in an argument. You cannot win. Suppose you succeed in shooting your opponent's viewpoint full of holes and prove him or her to be wrong. Then what? You feel great, but what about your opponent? You made that person feel inferior, hurt her or his pride, and created resentment. You may be right in your views, but you will never change the other person's mind. An argument is an exercise in futility. The only way to win one is to avoid it and retain the other person's goodwill.

An argument is easily avoided by agreeing with your opponent, even when you know that person is wrong. A *difference of opinion* is needed for an argument. Agreement with your opponent removes the cause of the argument and does not destroy the relationship. Keep your opinions to yourself and avoid trouble.

If someone loses their temper and you control yours, no problem exists. If you lose your temper and they control theirs, no problem. A problem occurs when both people lose their tempers. There is no communication during the yelling, just noise and bad feelings.

An argument can be avoided by changing the subject, or by asking for an explanation. Listen to the explanation and select areas of agreement. Everyone likes a good listener, especially when that person agrees the opinion being expressed. A potential argument is thus avoided; the topic is easily changed, without causing hard feelings.

This is not a question of being dishonest. It is simply a matter of avoiding trouble and using good people skills. Being friendly, courteous, and considerate creates friends and maintains good relationships. Arguments, criticism, and fault-finding will destroy friendships and cause bad feelings.

A PERSON'S NAME IS IMPORTANT

It is a serious mistake to forget or to misspell a person's (especially a customer's) name. People place an amazing amount of importance on their name. They enjoy hearing it spoken, or seeing it appear in print. People are proud of their name and appreciate such recognition. The average person is more interested in his or her own name than any other. When you say a person's name, you compliment that person and capture their attention.

Many people cannot remember names because they don't take the time and effort to fix a name in their mind when they first hear it. When you are introduced to a person, take the time to get the name correct. If necessary, say, "I'm sorry. I didn't hear your name clearly." Ask the person to repeat the name and possibly give the correct spelling. They will gladly oblige and appreciate your asking. Repeat the name to be sure you have it right. This fixes the name in your mind. Then use the

person's name in conversation to capture their attention and gain goodwill. The importance of remembering and using names cannot be overemphasized.

BECOME INTERESTED IN OTHER PEOPLE

If you want others to like you, you must become genuinely interested in them. Discover what makes them tick. Identify their strengths and weaknesses. Ask questions to start a conversation, then be a good listener. Remember special items that are important to the person you are dealing with.

When you become interested in others, they become interested in you. To be effective, the interest must be sincere. It becomes a ***win-win situation*** in which both parties benefit and communication is easy.

SMILE AND BE FRIENDLY

Your face can convey a message that speaks louder than words. A frown or scowl can cause people to become defensive. However, a winning smile is a friendly gesture that breaks down defenses. An insincere grin doesn't fool anybody, but a heartwarming smile is overwhelming and cannot be resisted. People who smile are easy to talk to. The effect of a smile is powerful and even can be detected over the telephone. A friendly "smiling voice" can capture your attention. For this reason, telemarketing businesses are constantly searching for people with friendly smiling voices.

WHEN WRONG, ADMIT IT

People learn best by making mistakes, and *nobody* is right all the time. When you tell *other people* they are wrong, however, you are asking for trouble. This is a personal attack on their intelligence, judgment, pride, and self-respect.

People often are *prejudiced* and suffer from preconceived notions, jealousy, suspicion, fear, envy and pride. If you are opinionated and inclined to tell people they are wrong, be prepared for failure. You cannot change a person's mind by telling them they are wrong.

Keep an open mind and examine the situation. Begin with a smile and say, "I may be wrong; let's examine the facts." Adopt an understanding attitude and show respect for the other person's opinion. Being diplomatic and courteous avoids trouble and leads the customer to be reasonable. You will never get into trouble by admitting you *may* be wrong.

When you actually *are* wrong, have the courage to admit it. Most people foolishly try to defend their mistakes. It takes courage to admit a mistake, but it is a smart move. People expect you to defend yourself with excuses and explanations. They are prepared to destroy such a defense, but will admire you for admitting the mistake and accepting the blame. Everybody makes mistakes, but few have the courage to admit it.

Another strategy is to steal your opponent's argument by accepting the blame and condemning *yourself* for being wrong. For example, you might say "I should have known better," "I'm ashamed," "I should have been more careful," or "There is no excuse for my mistake." It is easier to accept self-criticism than hear it from others. Say all the things the other person is thinking, or intends to say, before they have a chance. Odds are greatly in your favor that the other person will adopt a generous, forgiving attitude and minimize your mistake. Try it. You'll be pleasantly surprised.

HOW TO SHAKE HANDS

It is important to make a good ***first impression*** when being introduced. In business, a handshake is customary when saying hello or goodbye. When performed properly, a handshake will make a good impression. Unfortunately, many people do not know how to shake hands and thus make a bad impression. They fail before getting started.

A firm handshake, done with enthusiasm, is best. It should not be too quick or too prolonged. A limp or weak handshake gives the impression of weakness and lack of character. A very strong squeeze indicates a pushy person with an overbearing personality. Avoid the two extremes and use a firm handshake, to make the best impression.

When shaking hands, always look the other person directly in the eye . This eye contact is important, since most people feel it shows sincerity and good character. Failure to maintain eye contact gives an impression of weakness, insincerity, and poor character.

As you shake hands, smile and *mean* it. Show enthusiasm. A sincere smile and friendly attitude puts the other person at ease because they like you. All defensive mechanisms are destroyed and a new friendship begins.

Be certain you get the name right and remember it! Repeat the name by saying, "Glad to meet you, John," or "It's a pleasure to meet you, Mr. Smith." This repetition not only helps fix the name in your mind, it pays the other person a sincere compliment.

The same procedure is used when saying goodbye. Be certain the other person retains good feelings about you. A good beginning and a good ending will tend to overshadow any minor problems that have occurred. When a person likes you, they will usually overlook small mistakes. If they dislike you, those mistakes are remembered.

PHYSICAL APPEARANCE

Physical appearance and your manner of dress conveys a strong message regarding your personality, Fig. 29-2. A sloppy appearance is seen by customers as indicating sloppy work habits and poor character traits. There is no excuse for being dirty or leaving a mess for someone else to clean up. An extravagant or flamboyant

Fig. 29-2. First impressions are important in how people respond to you when you make a service call. A neat, clean uniform, a friendly smile, and a firm handshake will go a long way toward making a good impression on the customer. (Sporlan Valve Co.)

appearance indicates a person who seeks recognition at any cost.

It is important to dress appropriately. People judge you according to appearance and become uneasy when the picture doesn't "fit." For example, a service technician arriving at the door in a tuxedo and top hat (or swim trunks and beach sandals) would not inspire confidence in the customer.

A clean uniform is an asset in helping to convey the right picture. Service technicians frequently wear jeans and an appropriate work shirt. These are also acceptable if they are clean. Quality of the clothing is not as important as being clean and neat. Proper dress also requires a clean shave, trimmed beard, and combed hair. Good personal hygiene is another basic requirement for a successful technician.

Your appearance is a prime indicator of your personality and quality of work. It shows respect for yourself, your company, and the customer.

SHOW RESPECT FOR OTHERS

Many people try to win others to their way of thinking by monopolizing the conversation. They seem to believe that "He who talks loudest and longest wins the argument." This accomplishes nothing useful–it certainly doesn't change the other person's mind. Let the other person speak and explain his or her viewpoint. Ask some questions and let the person answer. If you disagree, *do not interrupt.* People find it hard to pay attention to you when their own ideas are crying for expression. Listen patiently and keep an open mind. Be sincere and encourage the other person to express her or his viewpoint fully.

DEALING WITH ANGRY CUSTOMERS

Angry people are most often basically nice individuals who have had a bad experience. They feel let down, disappointed, frustrated, and upset. By the time the customer is able to complain, he or she has most likely already reviewed several possible arguments. The customer is in the "attack mode" and is armed for verbal battle.

Let the customer speak. The angry person has rehearsed and needs to speak out; he or she will not calm down until this need is satisfied. Don't interrupt and avoid becoming emotionally involved. Ignore personal comments or threats. Don't defend yourself or your company. Be sympathetic and *listen carefully.* Analyze what is being said and figure out exactly *why* this person is upset. Try honestly to see things from the customer's point of view.

Reply only when the customer indicates she or he is ready to hear what you have to say. Let the person know that you understand the problem and sympathize. For example, you might say, "I don't blame you for being upset. I would be, too." Don't insult the customer's intelligence by making excuses or explanations. What happened is "water over the dam."

Concentrate on the solution: ask the customer what can be done to make things right. Most customers want far less than you think. A replacement or repair, a minor adjustment to the bill, or an apology will often resolve the problem. Let the customer know you are genuinely interested in helping. Give the customer what he or she wants and do it quickly and effectively.

Always be receptive to customer complaints. Every business produces some unhappy customers. This situation can be turned around if they have an opportunity to voice their complaints, know they are being heard, know someone cares, and have their problem solved quickly and effectively.

SELLING SERVICE

The service technician is a field representative of the company he or she works for. Good mechanical skills and good people skills will reflect favorably upon the company and lead to personal advancement. You must remember that you are selling *service,* and that performance speaks louder than words. See Fig. 29-3. A company cannot afford service technicians who cause customer problems.

The customer is the most important person in any business. Without customers, you would not have a

job. The customer is well aware of this business principle and has every right to expect good service and fair treatment. If the customer does not receive good service and fair treatment, he or she will go elsewhere. You would, too.

TEN COMMANDMENTS OF GOOD SERVICE

The "Ten Commandments of Good Service" have been around for a long time, but the principles they illustrate never go out-of-date:

1. Customers are not dependent on us. We are dependent upon them.
2. Customers are not an interruption of our work. They are the purpose of it.
3. Customers do us a favor when they call. We are not doing them a favor by serving them.
4. Customers are part of our business, not outsiders.
5. Customers are not cold statistics. They are flesh and blood human beings with feelings and emotions like our own.
6. Customers are not people to argue or match wits with.
7. Customers are people who brings us their wants. It is our job to fill those wants.
8. Customers are deserving of the most courteous and attentive treatment we can give them.
9. Customers are the people who make it possible to pay your salary.
10. Customers are the lifeblood of any business.

Fig. 29-3. As a field representative of the company you work for (or your own company), your performance, attitude, and appearance will speak louder than words. Demonstrating professional competence and demonstrating your desire to solve the customer's problem will help you succeed in the HVAC field. (Elf Atochem)

SERVICE CALLS

Service calls require constant use of good people skills. Customers feel safe and secure when they have confidence in your ability to solve their problem. They are always apprehensive when something is wrong with their heating and cooling equipment. They have questions like, "Will it catch fire or explode?" "Will it be out of service for days?" "Can it be fixed?" "How expensive will the repair be?" The service technician's appearance, attitude, and actions will either resolve these fears, or make them worse.

Customers usually do not have the technical knowledge to know if the work is done properly. That is why they judge the service technician by the way she or he looks and acts. A poor appearance, or a bad attitude, can cause the customer to question your ability. He or she will not trust you and worries about being charged for work that was not necessary. The customer may worry that the basic problem was not fixed and that another service call will be required.

If a ***callback*** does become necessary in this situation, the customer may demand a different technician and an adjustment on the bill. Can you imagine the telephone conversation between the dissatisfied customer and the Service Manager? If such situations occur repeatedly, the technician's future with the company will not be bright.

BEGINNING THE SERVICE CALL

Upon arrival, introduce yourself and make sure you understand the problem. Ask questions about why the customer called. Effective troubleshooting requires a clear understanding of the problem. This saves time and the possible embarrassment of solving the *wrong* problem. Such questions assure the customer that you are serious and builds trust and confidence in your ability.

CUSTOMER SAFETY AND SECURITY

People have a basic need for safety and security. They feel threatened by anything that is not familiar. An equipment malfunction may cause a sense of danger, and this fear is real. *Never* make light of this fear. The customer's fears will only be overcome when repairs are made and fully explained. There is always a reason for fear, and it is important to discover the reason. Ask questions to get the facts, and assume the answers are true. This convinces the customer that you take the problem seriously and builds confidence.

So-called "nuisance" service calls (for example, because an air conditioner is "making a funny noise") are

just as important as a call to do a major overhaul. Customers usually are not familiar with the technical facts of the equipment. They depend on you for help. Your explanation of the facts should gain their confidence and calm their fears. They will appreciate your help and gladly pay to have their sense of safety and security restored.

LEGITIMATE CUSTOMER COMPLAINTS

Sometimes customers have a perfect right to be upset. Agree with them, sincerely apologize, and show respect for their complaint. Customers need to be respected as persons. When they have a legitimate complaint, you should agree with the justice of it. Be reasonable and try to find a way to solve or lessen the problem.

CLOSING THE SERVICE CALL

It is important at the beginning of the service call to know exactly what the problem is. At the end of the service call it is necessary to assure the customer that you solved the *right* problem. The customer deserves to know what you have done and what it means. It is not good enough to say, "I found the problem and fixed it." In terms the customer can understand, explain what you have done and what it means.

Sometimes the customer expects too much, or has called the wrong company to solve the problem. (For example, a house wiring defect that is affecting the air conditioner. The customer needs an electrician, not an HVAC technician.) If you are unable to correct the problem, clearly explain to the customer what must be done to correct it. Offer suggestions so that the customer can select a course of action.

SUMMARY

Customers usually will judge the quality of work and service by the way they react to the technician's attitude and appearance. Trust and confidence is gained by showing proper respect to the customer as a person and by doing the work efficiently. Be sure to get the customer's name right and to use it when talking to the customer. Avoid arguing, since there is no way you can win.

You can give the customer a sense of security by solving the right problem. This is done by making sure you know why the customer called. At the close of the call, you must explain to the customer what you did and what it means. Customer problems are important because they are the basis of your job.

TEST YOUR KNOWLEDGE

Please do not write in this text. Place your answers on a separate sheet.

1. The quickest road to success is to combine good ________ skills with good people skills.
2. True or false? The first rule of people skills is to make sure all criticism is constructive in nature.
3. What is the easiest way of avoiding an argument?
4. Name two other means of avoiding an argument.
5. ________ a person's name after you are introduced will help to fix it in your mind.
6. A ________ situation is one in which both parties benefit.
7. When you are wrong, you should:
   a. Become defensive.
   b. Ask questions.
   c. Admit your mistake.
   d. Bluff.
8. True or false? If you are a very skilled technician, you don't have to dress and behave conventionally.
9. When dealing with an angry customer, it is important to be ________ and listen carefully.
10. When customers have confidence in your ability to solve their problem, they feel ________ and ________.

DICTIONARY OF TECHNICAL TERMS

A

ABS: Plastic pipe and fittings made from acrylonitrile-butadiene-styrene.

Absolute pressure: Any pressure above a perfect vacuum, expressed in terms of pounds per square inch absolute (psia).

Absolute zero: Point at which all heat is removed from the substance, and molecular motion stops completely (-460°F or -273°C).

Absorb: To soak up.

Accumulator: A small reservoir used as a safety device to trap any liquid refrigerant that did not evaporate in the evaporator.

Acetone: A liquid solvent used in acetylene storage tanks.

Acetylene: Fuel gas that produces the highest temperature for soldering, brazing, or cutting.

Acids: Corrosive chemical compounds.

ACR: Copper tubing used for air conditioning and refrigeration work.

Adapters: Special fittings used to quickly and easily connect different types of piping.

Adsorb: To collect substances on a surface in a condensed layer.

AEV: See "Automatic expansion valve."

Air duct system: The network of tubes that is used to control airflow to and from the conditioned space.

Air off: The air leaving the evaporator (also referred to as "supply air").

Air on: Air entering the evaporator (also referred to as "return air").

Air space: The area being cooled.

Alkybenzene oils: Synthetic compressor oils manufactured from propylene and benzene.

Alloys: Compounds of two or more metals.

Alternate: To move first in one direction, then the other.

Alternating current: Current that reverses direction many times each second.

Ambient temperature: As used in the refrigeration field, this term refers to the temperature surrounding the object under discussion, such as a motor or condenser.

American National Standard Thread: A group of three main series of threads, consisting of National Fine, National Coarse, and National Pipe.

Ammeter: Instrument used to measure electron flow.

Ampacity: The amount of current a conductor can safely carry without becoming overheated.

Amperage: The measurement of current flow in units called "amperes."

Amperage interrupting capacity (AIC): Point beyond which a circuit protection device can no longer interrupt current flow.

Ampere: The unit of measure for electrical current flow.

Angle: Figure formed by two lines drawn from the same starting point.

Annealed: Metal (such as copper tubing) that softened by heating it to a bright cherry red color and permitting it to cool. This allows it to be bent easily.

Arbor: The spindle or axle used to attach a cutting tool, such as a saw blade to a motor.

Arcing: Electrical sparks that occur between contacts as they open or close.

Area: Square measure found by multiplying length times width, or (for a circle) the pi value of 3.1412 by the radius squared.

Armature: The movable arm of a relay.

Aspirator hole: A small hole drilled in side of the accumulator dip tube. It permits small quantities of oil to enter the outlet tube and be drawn back to the compressor.

Atmospheric air: A mixture of various gases and water vapor.

Atmospheric pressure: Pressure exerted by air upon objects on the earth's surface. At sea level atmospheric pressure is 14.7 pounds per square inch (101.3 kilopascals).

Atom: The smallest particle of any element.

Atomizing: The process of converting a liquid into a spray of fine droplets.

Augers: Term used to describe screw-like devices used in pairs in a screw compressor.

Automatic expansion valve: A pressure-type control that is installed in the liquid line at the evaporator inlet.

Automatic gas valve: Valve used to start and stop flow of gas to the burners.

Automatic off-time defrost: Method that uses an inexpensive timer that turns the condensing unit off for two hours each evening.

Auxiliary heat: Supplementary heat used with a heat pump for cold weather. It is usually provided by staging electric heating elements.

Axial: Propeller-like (term used to describe fan blades).

Azeotropic blend: The combining of three or more refrigerants.

Azeotropic mixtures: Liquid mixtures of two or more refrigerants that combine to form a new single refrigerant.

B

Backfire: A condition that causes the brazing torch flame to go out with a loud cracking sound.

Backseated: A valve position in which flow through one passage is closed off, while flow through another passage is unrestricted. The opposite of frontseated.

Balance point: For a heat pump, the point where the heating ability of the device equals the heat loss of the building.

Balanced port valve: Construction of this valve equalizes opening and closing forces, compensating for a wide range of head pressure changes.

Basic refrigeration cycle: Process in which a circulating refrigerant absorbs unwanted heat at one location and carries it to a place where that heat can be discarded.

Bearing: Lubricated support for a rotating shaft.

Bimetallic: A disc used to make and break a set of contacts. The disc is made by fusing together two thin circular discs of different metals, usually steel and copper, that expand at different rates when heated.

Black oxides: Contaminants that form by the combining of oxygen and copper during brazing.

Bleed port: Valve located on the oil pump for bleeding air from the system.

Bleed resistor: One that is installed to permit electrons trapped in one side of the capacitor to slowly migrate to the empty side until the two sides are equal.

Bleedover: Condition in which a small amount of high-side pressure is vented into the low-pressure side of the system during the off cycle.

Blind hole: One that does not penetrate completely through a component.

Blind rivet: Permanent metal fastener used to join two pieces of sheet metal with a strong connection that will not loosen with vibration.

Blower relay: Device that energizes the blower motor during the cooling cycle.

Blower section: The motor and centrifugal (squirrel-cage-type) fan that circulates air through the furnace for treatment (heating or cooling).

Boiling point: Temperature and pressure at which water and other liquids change state and become a gas.

Bolt: A fastener that is used with a nut and normally used for fastening heavy metal parts together.

Bolt extractor: A threaded tool used to remove a broken bolt or screw.

Boyle's Law: Gas law that explains the relationship between pressure and volume. It states: "The pressure of a gas varies inversely (opposite) as the volume, provided the temperature remains constant."

Brazing: The process of joining two pieces of base metal with the use of a filler alloy at a temperature higher than 840°F(450°C).

British Thermal Unit (Btu): The basic unit used to measure the quantity of heat. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Burner fan: Centrifugal-type fan, located inside the burner assembly, that supplies primary air for mixing with oil.

Busbar: A metal bar that serves as a common connector for electrical circuits.

Bushing: Sleeve around a shaft.

Bypass line: Tubing that permits refrigerant to bypass the expansion valve when the coil is operating as a condenser in a heat pump installation.

C

Cad cell: Common name of the cadmium sulfide flame detector used to detect loss of flame on an oil-fueled furnace.

Cadmium-bearing alloys: Brazing alloys containing cadmium, which is a toxic metal when molten. It emits highly poisonous cadmium oxide fumes that can cause illness or death.

Callback: Return visit necessary to correct a problem that was not resolved on the initial service call.

Cap screws: Set screws that have heads.

Capacitor: Electrical component that acts as a throttling (choking) device to limit the number of electrons flowing in the start winding of a motor.

Capacitor-start, capacitor-run (CSCR) motor: The most powerful of the single-phase induction motors, providing both high starting torque and high running torque.

Capacitor-start, induction-run (CSIR) motor: Type of motor commonly used in situations where the motor must start under a heavy load, but once started can operate with just the run winding.

Capacity control: Term used for various methods of control intended to prevent the compressor from cycling on and off rapidly.

Capillary action: The process where the alloy automatically fills the gap between the pieces of base metals.

Capillary tube: A length of small copper tubing that has a tiny, accurately sized inner diameter.

Carburizing flame: The flame (also called a "reducing" flame) that results from supplying excess acetylene.

Cartridge fuses: Larger-capacity fuses that fit into special holders.

Case: In a commercial installation, an individual cooling system. A grocery store will typically have a number of cases operating at different temperatures.

Celsius: Temperature scale used in most countries of the world, in which the freezing point of water is 0° and the boiling point is 100°.

Centigrade: Literally, "hundred steps". Original name for what we now call the Celsius scale, which has exactly 100 divisions between the freezing and boiling points of water.

Centrifugal blades: "Squirrel cage" blades used for blowers.

Centrifugal switch: Device that opens or closes a switch when a motor exceeds or drops below a designated speed.

Centrifugal: Term used to describe a force or movement outward from the center of a rotating object.

CFCs: See "Chlorofluorocarbons."

cfm: See "Cubic feet per minute."

Chamfer: A beveled edge.

Change of state: Phenomenon that occurs when the temperature and speed of the moving molecules reaches a certain level. At this precise temperature, the molecules will rearrange themselves into a different pattern.

Charging: Adding refrigerant to a system.

Charles's Law: Gas law that explains the relationship between pressure and volume. It states: "At a constant pressure, the volume of a confined gas varies directly as the absolute temperature; at a constant volume, the pressure varies directly as the absolute temperature."

Cheater: Pipe extension used to increase leverage of a wrench.

Check valves: Valves that prevent flow of refrigerant in the wrong direction.

Cheek: The side of a hammer head.

Chlorofluorocarbons: Refrigerants that are composed of chlorine, fluorine, and a hydrocarbon (methane).

Circuit: In electrical terms, a pathway for current flow.

Circuit protection devices: Fuses and circuit breakers.

Clamshells: Sections of the heat exchanger. Burners fit into special chambers built into the bottom of the clamshells.

Clearance pocket: Space formed at the top of the compressor cylinder to prevent the piston from striking the valve reed.

Clockwise: Rotation to the right.

Close nipple: Short section of pipe threaded along its entire length.

Coefficient of performance (COP): A measurement of heat pump efficiency obtained by dividing heat output, in Btu, by power input (in Btu/watt).

Combination fan/limit control: This control regulates operation of the blower motor and provides safety protection against overheating of the furnace.

Combination heating-cooling thermostat: Control that must be installed when adding air conditioning to an electric furnace system.

Common: A term used to describe the wire that is used to connect one end of the run winding and one end of the start winding.

Compliant: Term used to describe the yielding scrolls inside a scroll compressor. They will "give" or separate from each other in the presence of liquid.

Compound gauges: Special gauges that display two scales is used to read pressures both above and below atmospheric.

Compression fittings: Pipe and tubing fittings used for heating applications that involve only low pressure.

Compression: Pushing force.

Compression ratio: A measurement obtained by dividing the absolute suction pressure (psia) into the absolute condensing pressure (psia).

Compressor: Device that "squeezes" low-temperature, low-pressure refrigerant gas into a small volume, which will result in a high-temperature, high-pressure gas.

Condensate pan: Container located under the evaporator to catch defrost water.

Condensate water drain: Hole or hose that keeps water resulting from condensation from accumulating inside the case.

Condensation: Changing from a gas to a liquid. Heat is released in the process.

Condense: Change to a liquid state.

Condenser: A heat exchanger designed to remove heat from the superheated refrigerant vapor, causing the vapor to condense (change state) back to a liquid.

Condensing unit: All the equipment necessary to reclaim the refrigerant gas and convert it back to a

liquid. It consists of the compressor, condenser, hot gas discharge line, condenser fan, electrical panel box, and some accessory components.

Conductance: Ease with which current flows.

Conduction: The flow of heat through a substance from one end to the other.

Conductor: A solid wire or a group of wires twisted together. Stranded wire: A group of wires twisted together.

Conductors: Pathways that carry electrical energy from place to place.

Conduit: Metal piping used to enclose and protect electrical wires.

Contactor: An electromagnet used to control multiple *heavy duty* contacts that are opened or closed at the same time.

Contacts: Electrical switch components that opened or closed to energize or deenergize a circuit.

Contaminants: Sludge, acid, corrosion, and other foreign substances in a refrigeration system that can cause various system problems.

Continuity: Existence of a complete path for electron movement from one point to another.

Control circuit: A low-voltage (24V) circuit used to open or close a line-voltage (120V) circuit.

Convection: The movement of heat by means of a carrier, such as air or water.

Conversion devices: Machines that change electrical energy to some other form to do some type of useful work.

Corrosion: Rusting and related chemical deterioration of metal.

Coulomb: The measure of the number of electrons flowing past a given point in one second. This unit of measurement equals 6.25×10^{18} electrons.

Counterclockwise: Rotation to the left.

Counter-electromotive force (c-emf): Counter-voltage that acts like a resistance.

Coupling: Fitting used to connect two lengths of hard copper tubing or pipe.

Cracked: State in which a valve is opened slightly by turning the stem about one or two turns.

Crankcase heaters: Electric heaters used to keep the crankcase oil warm to prevent condensing of refrigerant vapor in the crankcase.

Crankcase pressure regulator: Valve used to protect the compressor from excessive suction pressure, most often at start-up.

Crankshaft: Device used to change the rotary (circular) motion of the electric motor into a reciprocating (up-and-down) motion.

Crest: The top edge of two adjoining threads.

Crimp: Squeeze.

Criticism: Assessment of a person's actions or results (often seen as negative).

Cross-charged: Term that refers to a sensing bulb that is charged with a refrigerant different from the one used in the system.

Crossover igniter: A slotted length of metal that acts as a bridge between burners.

Cryogenic: Term that refers to refrigeration systems capable of producing temperatures below -250°F. They are used in laboratories to perform various scientific experiments.

Cubic feet per minute (cfm): Measure of the air volume that a fan can move.

Cubic measure: The measure of volume, found by multiplying height, length, and width.

Current: The flow of electrons in a conductor.

Customer relations: The ability to gain customer confidence and trust by effectively and promptly solving service problems.

Cut-in point: The temperature setting that causes the thermostat contacts to close.

Cut-out point: The temperature setting causing the thermostat contacts to open.

Cutting oxygen lever: A lever-actuated valve on an oxy-acetylene cutting attachment, used to supply the stream of oxygen needed for cutting.

CVPC: Plastic pipe and fittings made from chlorinated polyvinyl chloride.

Cycling on the overload: Situation in which an overload condition causes the bimetallic disc to trip, shutting down the motor. After each trip, it requires more and more time for the bimetallic disc to cool and allow a restart.

D

Dalton's Law: Gas law that deals with a mixture of gases rather than a single, pure gas–to obtain the total pressure of a confined mixture of gases, add the pressure for each gas in the mixture.

Data plate: Metal plate, mounted on each compressor, which contains coded information that reveals construction details of the unit.

Dead leg: A grounded phase of a three-phase delta transformer.

Dead short: Connection that permits an unrestricted flow of electrons.

Decimal numbers: A whole number, plus any parts (or fractions) of the whole. A decimal point separates the whole number from the parts.

Decimal point: Dot used to separate the whole number from the parts in a decimal number.

Deenergized: Turned off (such as an electrical circuit).

Defrost cycle: Sequence of operations used to remove frozen moisture from the evaporator and restore it to full efficiency.

Defrost terminator thermostat: Control used to disconnect the heater when the evaporator temperature reaches about 50°F (10°C).

Degree: In geometry, one of 360 equal divisions of the perimeter of a circle. In physics, a subdivision of a temperature scale.

Dehumidifier: A refrigeration system designed specifically to remove moisture from air without affecting air temperature.

Dehydrate: Dry out.

Delta: Type of three-phase transformer with windings similar to a triangle in form.

Denominator: The bottom number of a fraction, indicating the number of parts required to make a whole.

Density: A measurement of how closely the molecules of a substance are packed.

Desiccant: A drying agent.

Desuperheating TEV: Valve that injects enough liquid refrigerant to cool the hot discharge gas to the recommended suction temperature.

Dewpoint: A term used to describe the point at which the air becomes saturated for a given temperature.

Diameter: A straight line across the widest part of the perimeter of a circle.

Diaphragm: Flexible disk or bellows that responds readily to pressure changes.

Die: A tool used to cut threads around the outside of a piece of metal.

Dielectric: An insulating material used in such devices as capacitors.

Differential: The difference between cut-in and cut-out points in a thermostatically controlled system.

Differential valve: Valve, controlling the bypass line, that opens when the pressure difference between the receiver and hot gas discharge exceeds a preset value.

Digits: The numbers 0 to 9.

Dimensions: Measurements of length, width, and depth.

Dip tube: Tube that extends to about one-half inch from the bottom of the receiver to assure only liquid enters the liquid line at the receiver outlet.

Direct current: Electric current that flows in only one direction.

Direct drive: Drive arrangement where the rotor is fastened directly to the crankshaft.

Discharge bypass valve: A modulating valve that controls hot gas bypass to automatically maintain a desired *minimum* evaporator pressure.

Discharge port: Hole through the valve plate of the compressor where hot gas is discharged.

Discharge service valve: Valve located on the high-pressure side of the system that allows the technician to take pressure readings and to control refrigerant flow to the compressor.

Disconnects: Heavy duty, manually operated contacts used for disconnecting large loads from the power source.

Disc-type compressor valve: A valve design that increases compressor capacity up to 25 percent by improving volumetric efficiency.

Disposable cylinders: Refrigerant containers that are discarded after use. They are not refilled.

Dissipated: Lost.

Double-pole, double throw (DPDT) switch: Switch that has two poles and two contacts for each pole, so two contacts are always closed and two contacts are always open. This switch makes it possible to control a variety of loads from one location.

Double-pole, single-throw (DPST) switch: Switch that has two poles and a contact for each pole, making it possible to open or close two circuits at the same time.

Double-pole breaker: Circuit breaker used to disconnect both hot wires on 230V, single-phase branch circuits.

Draft: Air movement or natural convection (the rising of less-dense hot air).

Draft control: Device is used on all gun-type oil burners to keep the flue pressure constant.

Draft hood: Connection point for the burner vents and the flue.

DSV: See "Discharge service valve."

Dual element: A type of fuse designed to permit an overload of short duration, but to blow instantly if a short circuit occurs.

Dual-pressure motor control: A combination of a low-pressure control and a head-pressure (high-pressure) safety control.

Dual-voltage motors: Motors manufactured to operate on either of two supplied voltages.

Dummy terminals: Terminals that have no effect on the operation of the relay, but provide connection points for splicing wires.

E

Eccentric: The crank throw in a motor-compressor.

Elbows: Fittings used to change direction of the tubing run. They are available in either 45° or 90° angles.

Electric defrost: System that uses electric resistance heating to perform the defrosting of domestic refrigerators.

Electric power: Measurement of the rate at which electrons are used to perform useful work.

Electrical symbols: Standardized simple drawings used for ease of communication in schematic diagrams.

Electricity: The energy released by the movement of free electrons from one atom to another.

Electrodes: In a capacitor, the two conductive layers of aluminum foil, that are separated by an insulating layer of specially treated paper.

Electromagnetism: The phenomenon of a magnetic field generated around a wire by electrical current flowing through it.

Electromotive force (emf): Potential difference, also called voltage.

Electronic ignition: A system that saves fuel by eliminating the continuously burning pilot flame. The pilot flame is ignited by an electric spark and burns only upon a call for heat.

Electronic leak detector: A unit, consisting of a probe and a case containing the electronics, that is used to detect the presence of halide refrigerant gas.

Electronic scales: Weighing devices with displays that can be set to show, in ounces, the amount of refrigerant being withdrawn from the cylinder and charged into the system.

Electrons: Particles in an atom's nucleus that have a negative charge.

Emergency heat switch: Control on a four-bulb thermostat used to energize auxiliary heat in a heat pump.

Energy efficiency ratio (EER): The ratio of energy produced (output) to energy used (input).

Enthalpy: The heat content of a vapor or liquid in Btu/lb.

Epoxy: A two-part material that chemically hardens. Used as a filler and an adhesive.

Equalizing: A balancing of system pressures.

Erratic: Term used to describe a valve that does not maintain a particular setting for any length of time.

Ester-based synthetic oils: Oils that are wax-free and have a low pour point and a low floc point.

Evacuating: Emptying a system with a vacuum pump.

Evaporation: Changing from a liquid to a gas. Heat is absorbed in the process.

Evaporator fan delay thermostat: Device used to delay restarting of the fan until evaporator temperature drops to about 5°F (-15°C).

Evaporator freeze-up: Situation in which an evaporator has become totally restricted by frost and ice buildup.

Evaporator: In a refrigeration or air conditioning system, the heat-exchanging device located within the area where heat is to be removed.

Evaporator pressure regulators: Special valves used to prevent evaporator pressure from falling below a set limit.

Evaporator unit: Portion of the system that absorbs heat from the refrigerated space. It consists of the evaporator, refrigerant control, evaporator fan, and some accessory components.

Exponent: A numeral that is placed above and to the right of a base number as an abbreviation to indicate a multiplication process. Also called a *power*.

Extended plenum system: System that combines rectangular duct with round duct.

Extension: Pulling force.

Externally equalized valve: Valve that resembles the internally equalized type, but evaporator pressure on the underside of the diaphragm is supplied from the evaporator outlet, rather than the inlet.

F

Factor: The base number used with an exponent.

Fahrenheit: Temperature scale most common in the United States, in which the freezing point of water is 32° and the boiling point is 212°.

Fail-safe setting: Timeclock feature that terminates a defrost cycle if temperature or pressure termination components fail to operate properly.

Fan cycle control: Device used to control the condenser fan or fans. When head pressure drops below acceptable limits, the fans are turned off.

Fan relay: Device used on oil furnaces with air conditioning to operate the furnace blower motor during the cooling cycle.

Fan switch: Control used to operate the blower motor.

Feeder service: Circuit to an electric furnace from the main disconnect or load center.

Ferrous: Term used to describe iron-containing metals.

Fillet: A bead of solder at the point where the joined pieces meet.

Filter: A cleaning device used to capture dust, lint, dirt, and other impurities from the circulating airstream.

Filter-drier: Device to absorb remaining moisture and catch any foreign particles circulating with the refrigerant after evacuation.

First impression: The feeling someone forms about you when you are first introduced.

Flame safeguard: Device that will detect loss of flame and shut down the furnace to prevent it from filling with oil.

Flare bonnet: Copper insert used to convert an ordinary flare nut into a cap nut.

Flare cap nut: Female nut that is used to seal off a male-threaded fitting.

Flare elbow: A fitting used to connect two flare nuts of the same size, while providing an accurate bend of either 45° or 90°.

Flare fittings: Those used in conjunction with the flaring process.

Flare nut: The most frequently used fitting. Flare nuts are sized by the hole through which the tubing is inserted.

Flare plug: Fitting used to seal a flare nut or similar female-threaded opening.

Flare tee: Fitting that makes it possible to connect a branch onto an existing line of copper tubing.

Flare union: A fitting used to connect two flare nuts of the same size.

Flaring: A process of expanding or spreading copper tubing so that the end of the tube has a funnel shape with a 45° angle.

Flaring block: Special tool used to hold tubing for enlarging in the swaging process.

Flash gas: The vapor that results from the sudden pressure drop (from high to low) as liquid passes through the TEV orifice.

Flashback: A condition in which the brazing flame burns back inside the tip. This condition is revealed by a shrill hissing or squealing sound.
Flexible coupling: Rubber sleeve used to extend and connect shafts.
Floodback: Liquid in the suction line, resulting from too much liquid being metered into the evaporator.
Flue: Vent pipe connected from the diverter box to the chimney.
Flutes: The two spiral grooves on a twist drill.
Flux: A chemical used to treat the clean surface of the base metal when soldering.
Flywheel: A pulley (sometimes weighted) that is attached to the external crankshaft of a motor.
Forced convection evaporator: One that has an electric fan mounted so as to increase the airflow through the evaporator.
Forced convection: Term for heating and cooling systems that use a fan or blower to circulate air.
Forced-feed system: Lubrication method that uses an oil pump to deliver oil, under pressure, to all bearing surfaces and other critical parts.
Fraction: In mathematics, a part of a whole, often written with one number above another number.
Fractional horsepower: Term used to describe motors rated at less than one horsepower.
Freeze-up: Condition in which an evaporator becomes clogged with frost, preventing airflow.
Freezing: The process by which a product's water content is changed to ice and its temperature is lowered to the desired level for storage.
Freon-12: Dichlorodifluoromethane, one of the first halogen/hydrocarbon refrigerants to be introduced.
Frequency: The number of complete cycles of alternating current that occur in one second.
Frontseated: A valve position in which flow through one passage is closed off, while flow through another passage is unrestricted. The opposite of backseated.
Frozen storage: The storage of an already frozen product at a constant temperature, usually 0°F (-18°C) or lower.
Fuel oil: Hydrocarbon fuel that is used for home heating and some industrial and commercial heating applications.
Full load amps (FLA): The operating ("running") amperage of a motor.
Full-floating: A piston pin that is free to rotate within both the connecting rod and within the piston.
Fuse: Device designed to detect excessive load current and open the circuit before danger arises through the melting of a fusible element.
Fusible element: Metal link in a fuse that overheats and melts when excess current flows through it. This opens the circuit and stops current flow.
Fusible link: Metal strip that will melt at a specified temperature to protect a heating element against burnout if the limit switch fails.

G

Galvanized: Metal that has been zinc-coated.
Gap: Space between objects, such as electrode tips.
Gauge manifold: A pressure-checking device that has both compound and high-pressure gauges, control valves, and connectors for hoses from the service valves.
Gauge pressure: Pressure expressed in pounds per square inch gauge (psig). Readings in psig measure only pressures *above* atmospheric–gauges are calibrated to read zero at atmospheric pressure.
Graduated cylinder: Device used for measuring an exact refrigerant charge. Such cylinders are very accurate.
Grilles: Inlets for return air.
Ground fault: An internal electrical problem that permits electron flow to the frame and makes the frame electrically live.
Ground fault circuit interrupter (GFCI): Safety device designed to protect a circuit from overcurrent and to protect people from potentially hazardous ground faults arising from the use of defective appliances or portable tools.
Grounded: Connected to the earth.
Gun-type burner assembly: Burner designed to produce the conditions needed to produce a steady hot flame inside the furnace.

H

Hacksaw: Saw with a metal frame and interchangeable blades, used to cut pipe, tubing, or other metal items.
Halide refrigerants: Refrigerants that combine a halogen with a hydrocarbon compound, such as acetylene, methane, or ethane.
Halide torch: A device used for detecting halogenated refrigerant leaks.
Halogens: The chemical elements fluorine, chlorine, iodine, and bromine.
Hand shut-off valves: Valves that make it possible to quickly isolate sections of a system for servicing. Used on commercial and industrial systems.
Hard soldering: See "brazing."
Hard solders: Silver-bearing brazing alloys that have melting temperatures that range from 1100°F to 1500°F (593°C to 816°C).
Hard-drawn: Term describing rigid copper tubing that cannot be easily bent.
Hard-start kit: A solid-state relay and a capacitor in a single package, used to resolve hard-start problems by turning a permanent split capacitor (PSC) motor into a capacitor-start induction-run (CSIR) motor.
HCFCs: See "hydrochlorofluorocarbons."
Head pressure control valves: Modulating valves used to solve low head pressure problems caused by low ambient temperatures.
Head pressure: Pressure on the high side of the system.
Head-pressure safety control: A device that will shut off the system if head pressure exceeds proper limits.

Heat anticipator: A small resistance heater, mounted inside the thermostat, that causes the thermostat switch to open just before room temperature reaches the desired level.

Heat content: The amount of heat in a substance.

Heat exchanger: Furnace section where heat is transferred from burning fuel gas to the circulating air. In a refrigeration system, the component that transfers heat from the warm liquid line to the cold suction line.

Heat load: The air to be cooled.

Heat pump: An air conditioning system capable of reversing refrigerant flow so that it can function as either a cooling source or a heat source.

Heat relays: Devices used to stage the elements of an electric heating system on and off.

Heat sink: Any heavy metal device, such as a valve or compressor, that tends to draw heat away from the brazing area.

Heating element: Resistance wire component used to generate the heat required for the conditioned space.

Height: Linear measure of one dimension (from base to top) of an object.

Hermetic: Airtight, or totally sealed against all external forces.

Hexagonal: Having a six-sided shape.

Hex-head: Bolts or other fasteners with a six-sided head for use with a wrench.

HFCs: See "hydrofluorocarbons."

High-pressure safety control: A device that stops the compressor if head pressure exceeds its setpoint.

High-pressure side: The condenser side of a refrigeration system.

Horizontal joint: A type of joint where the tubing and the fitting are on the same level and are heated equally.

Hot gas bypass valve: Valve that meters small amounts of hot gas into the suction line during low-load periods.

Hot gas defrost: Defrost method in which gas is taken directly from the hot gas discharge line and delivered directly to the evaporator inlet.

Hot gas discharge line: Copper tubing connecting the compressor to the condenser.

Humidistat: A moisture-sensitive switch.

Humidity: Moisture in the air.

Hunt and surge: Condition in which a valve fluctuates from fully open to fully closed.

Hydrargyrum: Mercury, from the Latin term for "liquid silver."

Hydrochlorofluorocarbons: Refrigerants that contain hydrogen atoms that cause the compound to be less stable in the atmosphere (and thus, less damaging) than CFCs.

Hydrofluorocarbons: Refrigerants that contain no ozone-depleting chlorine atoms.

Hydrostatic expansion: The expanding of a liquid when heat is added.

I

Ice Melting Equivalent (IME): The amount of heat absorbed in melting one ton (2000 lbs.) of ice in exactly 24 hours.

Ignition transformer: A step-up transformer (120V to 10,000V) that is mounted on top of the burner assembly of a furnace.

Improper fraction: One in which the numerator is the same or larger than the denominator.

in. Hg.: The abbreviation used to indicate inches of mercury in vacuum measurements. Hg. is the chemical symbol for mercury.

Incomplete combustion: Partial burning of fuel that produces substances dangerous to human health.

Indoor coil: Heat pump component that is either an evaporator or a condenser, depending upon whether the system is heating or cooling.

Induced magnetism: Magnetism that is caused by an electric current.

Induced voltage: Voltage that is generated in a conductor by a magnetic field.

Inert: Chemically inactive.

Initiate: To begin an action or sequence of events (such as a defrost cycle).

In-line freezing: Fast freezing is done using cryogenic refrigerants and equipment installed directly in the production line.

Inside diameter: The distance across the inside of a pipe or piece of tubing. Abbreviated ID.

Insulation: A nonconductive covering for electrical wires, intended to prevent shocks and energy loss.

Insulators: Materials that have very few free electrons and exhibit high resistance to electron flow.

Insulators: Substances that are poor conductors of heat.

Integral horsepower: Term used to describe motors of one or more hp.

Intensity: Strength (of a magnetic field, for example).

Internally equalized valve: One in which a special passage built into the valve body transfers evaporator pressure to the underside of the diaphragm.

International Thread: A standardized metric thread used in most parts of the world.

Interstage pressure: Pressure of gas when leaving the first stage of a two-stage compressor.

Isolated: Blocked off or segregated from the rest of a system.

Isolation relay: Device used on oil furnaces with air conditioning. It is used to control the heating cycle and also to separate the two control circuits.

J

Jaw-type pipe wrench: Wrench with serrated jaws to grip pipe.

Jumper bars: Flat copper pieces used to connect different motor terminals for easy change from one voltage to the other.

Jumper wire: Short wire installed to complete a connection from terminal to terminal.

K

Kelvin scale: Temperature scale using Celsius divisions, with absolute zero at 0°K. The freezing point of water is 273°K, and the boiling point of water is 373°K.

Kilojoule (kJ): In refrigeration work, the unit used to measure quantities of heat.

L

Ladder diagram: Another name for a schematic, so-called because power supply lines are drawn parallel to form the side rails of the ladder, and loads are drawn between the power source lines, forming the rungs.

Laminated: Assembled in layers.

Latent heat: Heat energy that causes a change of state, but no temperature change.

Latent heat of condensation: The process of changing a gas (or vapor) to a liquid. Heat must be removed.

Latent heat of freezing: The process of changing a liquid to a solid. Heat is removed. (Also called latent heat of fusion.)

Latent heat of melting: The process of changing a solid to a liquid. Heat must be added.

Latent heat of sublimation: The process in which a substance changes directly from a solid to a vapor, without passing through the liquid phase.

Latent heat of vaporization: The process of changing a liquid to a vapor. Heat must be added.

Lead end: End of a motor where the electrical connections are located.

Length: Linear measure of one dimension (usually the largest dimension) of an object.

Lever-type tubing benders: Tools calibrated to allow the making of accurate short radius bends up to 180°.

Limit switch: A safety device that cuts off the power supply if the furnace becomes overheated.

Line starter: A contactor that has built-in overload protectors. It is used to operate and protect three-phase motors.

Line voltage: The power supply.

Liquid charging: Charging a system with refrigerant in a liquid state.

Liquid line: Copper tubing connecting the condenser outlet to the metering device called the refrigerant control.

Liquid receiver: Installed in larger systems, serving as a storage tank for excess liquid refrigerant.

Liquid receiver service valve: Valve located in the liquid line, at the liquid receiver outlet that allows the technician to take pressure readings and to control refrigerant flow to the receiver.

Liquidus: Point where melted solder flows as a liquid.

Load: Any electrical device that converts electrical energy to another form of energy.

Load center: Distribution panel that supplies electrical power to several branch circuits.

Locked rotor amps (LRA): High current flow that occurs when an electric motor starts.

Lockout: The process of locking the main electrical switch in the open position to safely perform equipment maintenance.

Logging: Problem caused by oil remaining in the evaporator due to low refrigerant velocity.

Low evaporator load: A condition in which the heat load cannot reach the evaporator surface.

Low-ambient thermostat: Control that prevents heat pump operation when outdoor temperature is very low.

Low-pressure motor control: Device used on commercial systems to control power supply to the contactor coil. The control responds to low-side pressures at the compressor.

Low-pressure safety control: A device that stops the compressor if suction pressure falls below its setpoint.

Low-pressure side: The evaporator side of a refrigeration system.

LRSV: See "Liquid receiver service valve."

Lubrication: The process of providing oil or other friction-reducing material to critical points of mechanical devices to lessen wear and prevent overheating.

M

Machine screws: Small bolts with screw-type heads.

Magnetic field: Lines of magnetic flux generated by an electric current.

Magnetism: The ability of a natural material or a field of force generated by an electric current to attract metals containing iron.

Major diameter: The widest measurement from the outside edges of the threads.

Makeup water: In a water-cooled refrigeration system, replacement for water lost due to evaporation.

Malleable: Term used to describe pipe fittings that are made of annealed (softened by heating) cast iron.

Manifold: Pipe that distributes gas to the burners through an orifice (outlet hole) in each burner.

MAPP: See "MPS."

Masonry anchors: Expanding devices that accept a fastener for mounting objects on a masonry surface.

Mercury: A metallic element that is a liquid at room temperature.

Mercury barometer: Measuring device for atmospheric pressure. It consists of a hollow glass tube, sealed on one end and open at the other, that is filled with mercury and turned upside down, with the open end placed in a dish half-filled with mercury.

Mercury switch: A switch that consists of two wire ends inside one end of a glass tube. A drop of mercury opens or closes the circuit.

Metering orifice: A device with a tiny hole that is installed in the liquid line at the evaporator outlet.

Microfarads (mf): Measure of the amount of energy a capacitor can store.

Migrate: Travel from one place to another.

Minor diameter: The smallest diameter, measuring from the inside of the threads.

Miscibility: The ability of oil to mix with refrigerant.

Modulates: Adjusts to changing conditions.

Moisture indicator: Disk that is highly sensitive to moisture, gradually changing color to reflect the moisture content in the refrigerant.

Molecule: The smallest physical part into which any substance can be broken down and still have its original identity.

Molly bolts: Expanding metal fasteners used to anchor relatively light objects to hollow walls.

Monochlorodifluoroethane: The most widely used HCFC, designated as R-22.

Montreal Protocol: An agreement signed by leading industrial nations, to substantially reduce production of ozone-depleting CFCs.

MPS: Methylacetylene-propadiene stabilized fuel gas, often referred to by its trade name, MAPP.

Mullion heaters: Resistance heaters that prevent condensation of moisture around refrigerator doors during periods of high humidity.

Multi-flame tip: Brazing tip that produces several small flames, which tend to wrap around the tubing being heated.

Multimeter: Electrical test meter that performs multiple functions.

Multiplexing: Connecting two or more evaporators to a single compressor.

Multi-speed motor: One that can be operated at different speeds, such as an air conditioner fan with high, medium, and low settings.

Mushroomed: Term used to describe the head of a chisel or other tool that is flattened and spread out from being struck.

N

National Electrical Code (NEC): Standard for electrical wiring and devices.

Net oil pump pressure: The difference between crankcase pressure and oil pump pressure.

Neutral flame: The flame that results from supplying equal amounts of oxygen and acetylene.

Neutral: In single-phase systems, a wire that has zero voltage.

Neutrons: Particles in an atom's nucleus that have no charge (are neutral).

Nominal: Approximate size.

Noncondensibles: Gases, such as atmospheric air, that cannot be condensed to a liquid state.

Nonflammable: Will not support combustion.

Normally closed: A switch or valve that is in a closed state until energized. Abbreviated NC.

Normally open: A switch or valve that is in an open state until deenergized. Abbreviated NO.

Nucleus: The center of an atom.

Number: A figure or word indicating a quantity.

Numerator: The top number of a fraction, indicating the number of parts available.

Nuts: Internally threaded metal pieces, usually square or hexagonal in shape, that are used with a bolt.

O

Off-cycle defrost: Method in which the fan runs continuously while the system is off, so warm air melts accumulated frost from the evaporator.

Ohm: The unit of resistance.

Ohmmeter: Device used to measure resistance.

Ohm's Law: Summary of the exact relationships among voltage, amperage, and resistance. Discovered at the beginning of the nineteenth century by a German scientist, Georg Simon Ohm.

Oil passages: Lubrication holes drilled in the crankshaft, connecting rods, and other components of a pump or compressor.

Oil pressure safety control: A control that stops the compressor if oil pressure falls below safe limits.

Oil separator: Component used to remove oil from refrigerant and return the oil to the compressor crankcase.

Open capacitor: One in which the electrical connection is broken, usually when one of the terminals becomes separated from its coil.

Open circuit: Lack of continuity; a broken path.

Open winding: A broken wire in the motor winding that is *not* touching the motor shell.

Orifice: A tiny, precisely sized hole used to control the amount of liquid entering the evaporator.

Outdoor coil: Heat pump component that is either an evaporator or a condenser, depending upon whether the system is heating or cooling.

Outdoor fan and defrost relay: Heat pump component that initiates the defrost cycle and turns off the outdoor fan.

Outdoor thermostat: Control device used in conjunction with a regular (single-stage) indoor thermostat to stage the heating elements in a two-stage heating system.

Outside diameter: The distance across the outside of a pipe or piece of tubing. Abbreviated OD.

Overcharge: An excess of refrigerant.

Overcurrent: Situation that occurs when too much current flows through a wire, damaging the insulation.

Overload: Electrical current in excess of the normal flow for a given circuit. Also, the electrical safety device designed to protect the compressor motor from an overload.

Oversized: In reference to a refrigeration system, this term means having more capacity than the minimum needed.

Oversizing: Specifying a transformer with a secondary that is able to carry more than the minimum required amperage, so that it can accommodate the load(s) connected to it.

Oxidation: A process in which oxygen atoms combine with the copper atoms to form copper oxide.

Oxidizing flame: The flame that results from supplying excess oxygen.

Oxy-acetylene torch: A torch burning a mixture of oxygen and acetylene as a heat source for brazing.

Ozone depletion: The eroding of the ozone layer of the atmosphere caused by chlorine gas from CFCs and other sources.

P

Parallel: Connected from one power leg to the other in an electrical circuit.

Partial vacuum: Any pressure less than atmospheric.

People skills: The skills that are needed to work well with people.

Percent: Amount equal to 1/100 of a number.

Perfect vacuum: Theoretical state in which all atmospheric pressure is removed.

Permanent split capacitor (PSC) motor: A split-phase motor with a design change that increases running torque.

Permeation: The process of gas seeping through the walls of refrigeration hoses.

Phases: The conducting loops in a generator.

Physical states: Three forms in which most substances can exist–solid, liquid, or gas.

Pickup voltage: Point where counter-emf is sufficiently high to allow energizing of the relay coil.

Pictorial diagram: One that shows the physical appearance, component locations, wiring connections, and internal arrangement of a piece of equipment.

Pig tail: Short copper tube on a compressor to which a Schrader valve can be brazed.

Pilot flame: A small gas flame used to ignite the flame on the main burners.

Pilot valve: Device that automatically controls the pressure difference at each end of the piston on a heat pump reversing valve.

Pipe compound: Paste material normally brushed onto the threads before assembly to ensure a strong, leakproof seal.

Pipe die: A special tool used to cut threads on the outside of steel pipe.

Pipe fittings: Components used to join sections of pipe.

Pipe thread: Thread that is tapered 1/16 in. for every inch of length.

Pipe vise: Special tool used to securely hold steel pipe in position for cutting and threading.

Piston: The device that moves up and down inside the compressor cylinder to compress refrigerant gas.

Pitch: The particular degree of angle to which fan blades are twisted.

Place value: In mathematics, the special position occupied by a digit located to the left or right of a decimal point.

Plastic range: The range of temperature between the solidus and liquidus points of a solder.

Plates: See "Electrodes."

Plenum: The supply air chamber of a furnace.

Pointer flutter: Pressure pulsations that cause a gauge pointer to swing above and below the actual pressure reading.

Points: Teeth around the opening or a box-end or socket wrench that grip the edges of the nut or the bolt head.

Poles: Two or more stationary electromagnets positioned at opposite sides of a circle inside the motor. They have opposing magnetic polarity. Also, an electrical switch component used to open or close contacts.

Polyalkaline glycols (PAGs): The first synthetic oils developed specifically for use with new refrigerants, such as HFC 134a.

Polyphase generation: Electric power production using a generator that rotates three different conducting loops at the same time.

Positive temperature coefficient (PTC) ceramic thermistor: A device that reacts rapidly to temperature change by greatly increasing its resistance to current flow.

Potential difference: The situation that exists when the electrical charge (positive vs. negative) between two points is not in balance.

Power factor: A measure of transformer capacity.

Preheat flame: A series of small flames that heat the metal to be cut until it glows bright orange. Oxygen is then supplied to make the cut.

Preheat valve: Wheel-type valve used to regulate gas flow on an oxy-acetylene cutting attachment.

Prejudiced: Term used to indicate a person has made a judgment on a person or situation before learning the facts. Also used in the sense of "biased."

Pressure control: Device that functions as a switch, turning the system on and off, as a result of changing low-side refrigerant pressure, to maintain temperatures within the desired range.

Pressure drop: Decrease of pressure in a piping system, caused by restrictions to flow.

Pressure regulator: Device used to reduce cylinder pressure to working pressure.

Pressure tap plug: Plug used to check pump pressure to the nozzle.

Pressure-operated switches: Switches that respond to rising or falling system pressures. They are often used as the primary control of a system.

Primary air: Combustion air that is drawn into the burner by the jet of gas as it enters. It is mixed thoroughly with gas inside the burner before delivery to the ports.

Primary control: On an oil-fueled furnace, the package that contains all the components necessary for safe operation of the burner motor and ignition transformer.

Primary controls: In air conditioning and refrigeration systems, those used to start and stop the condensing unit when certain temperatures or pressures are reached.

Primary winding: In a transformer, the winding through which the incoming current flows.

Profit margin: The difference between cost and selling price. Also called *markup*.

Proper fraction: One in which the numerator is smaller than the denominator.

Protons: Particles in an atom's nucleus that have a positive charge.

Protractor: An instrument used to measure degrees and angles of a circle.

psi: Pounds per square inch. A measure of pressure.

psia: Pounds per square inch absolute, used for pressure measurements.

psig: Pressure expressed in pounds per square inch gauge. See "Gauge pressure."

P-traps: Fittings named for the shape into which the tubing is bent.

Pumpdown cycle: Operation in which all refrigerant is removed from the low-pressure side following each run cycle to avoid high suction pressure at start-up.

PVC: Plastic pipe and fittings made from polyvinyl chloride.

R

Radial: In a circular pattern.

Radial piping system: Air duct system that uses round pipe runs that extend from the supply plenum to each register.

Radiation: The transfer of heat by waves that are similar to light waves or radio waves.

Radius: A line from the center of a circle to its perimeter (half the diameter).

Rankine scale: Temperature scale using Fahrenheit divisions, with absolute zero at 0°R. The freezing point of water is 492°R, and the boiling point of water is 672°R.

Reactive: Form of resistance is found in situations involving devices which produce a voltage that is in direct opposition to the supply voltage.

Reamed: Description of tubing or pipe that has been scraped with a tool to remove burrs from a cut surface.

Recalibration: Periodic adjustment of a gauge or meter to ensure accuracy.

Reciprocating: Moving first in one direction, then the opposite (back and forth, or up and down).

Reclaim: To reprocess recovered refrigerants so that they meet new product specifications.

Recover: To remove refrigerant from a system and store it in a refillable cylinder.

Recovery: The process of removing refrigerant from a system.

Recycle: To clean recovered refrigerant for reuse.

Recycling units: Machines used to remove most contaminants from refrigerants withdrawn from a system and make the refrigerant suitable for reuse.

Red iron oxide: Rust that forms when oxygen from the air and moisture combine.

Reducing coupling: Coupling that is a different size on each end.

Refrigerant control: Device that meters the flow of liquid refrigerant into the evaporator.

Refrigerant distributor: On larger systems, the distributor receives refrigerant directly from the thermostatic expansion valve and divides it equally among all evaporator circuits.

Refrigerant: Substance that readily changes from a liquid to a gas, then is condensed back to a liquid for recirculation.

Refrigeration: The process of removing heat from where it is unwanted and carrying this heat to a place where it can be discarded.

Register: Supply air outlet.

Relative humidity: The term used to describe the amount of moisture held by one cubic foot of air.

Relays: Electrically operated switches that can be used to automatically disconnect the start winding and/or the start capacitor of a motor.

Reset: Manual switch used to restore a circuit breaker to its normal state.

Resistance: In electricity, anything impeding (working against) the movement of electrons.

Resistive: Type of resistance that remains constant (does not change).

Restrict: To decrease and control liquid refrigerant flow.

Restrictor: Device installed in the liquid line to meter the flow of liquid refrigerant into the evaporator.

Retrofitted: Updated or modernized after some period of being in use.

Returnable cylinders: Refillable heavy duty certified pressure vessels.

Reverse-air defrost cycle: Method that reverses fan direction, so that warm store air is used to defrost refrigerated food display cases.

Reversing relay: Device that, when energized, reverses wiring connections to the evaporator fans and thus reverses fan rotation.

Reversing valve: Four-way valve that controls direction of refrigerant flow in a heat pump.

Revolutions per minute: Unit used to measure the speed of motors and other rotating devices.

Riser: A vertical section of the suction line.

Root: The bottom area of two adjoining threads.

Rotary: Term used to describe a circular motion around a central point or axis.

Rotation: Circular movement around a center point (for example, turning of a motor shaft).

Rotor: Rotating part of the motor.

rpm: See "Revolutions per minute."

Run capacitor: The capacitor used on PSC motors to create better running torque.

Run winding: The winding of the stator coils in a motor.

S

Safety ground: The (green-wire) equipment grounding conductor or "earth ground."

Saturated conditions: A term often used to refer to the boiling/condensing point of a substance, which is dictated by a specific combination of temperature and pressure.

Saturated: Full; holding as much moisture as possible.

Saturation point: Condition in which the temperature/pressure combination of a substance is such that the substance can change its state.

Saturation pressure: Boiling point of a liquid.

Schematic diagram: An orderly method of presenting electrical circuits and components. The schematic shows the types of components involved and how they are connected in the circuit.

Schrader valve: A stem-type valve installed in a system for service access.

Screw thread: A helical ridge of uniform section formed inside of a hole (such as a nut) or on the outside of a fastener (such as a screw or bolt).

Screws: Threaded fasteners used to obtain good holding power and provide a means for repeatedly removing fastened parts.

Scroll compressor: One that involves the mating of two spiral coils (scrolls) to form a series of crescent-shaped pockets.

Secondary air: Air that is drawn into the burner chamber after ignition of the flame.

Secondary control: Safety device used to shut off the system if certain conditions exist.

Secondary winding: Transformer winding in which an electrical current is induced by the magnetic field in the core.

Semi-hermetic: A motor-compressor design that combines the benefits of the hermetic and open-type compressors.

Sensible heat: Heat that causes a change in temperature, but not a change of state.

Sensing bulb: Device located on the suction line at the evaporator outlet to control the operation of a thermostatic expansion valve.

Sensing element: See "Sensing bulb."

Sequencers: Devices used to stage the elements of an electric heating system on and off.

Series connection: In a commercial display freezer, an arrangement in which the refrigerant must travel through one shelf before going to the next.

Series: Electrical term for components connected one after the other in a circuit.

Series-parallel: Electrical circuit in which some components are connected *in series*, while others are connected *in parallel*.

Serrated: Having a toothed or ridged edge that keeps material from slipping while being cut.

Set screws: Headless fasteners used to anchor pulleys and fan blades to motor shafts.

Setpoint: One of the extremes of the range for which the thermostat is set.

Shaded pole motor: A specially designed, low-cost motor often used to operate small fans.

Shading coil: A single closed loop of wire on each pole of a shaded-pole motor. The loop produces a tiny magnetic field that is "out of step" with the main poles, aiding in starting the motor.

Shaft end: End of a motor where the rotor shaft exits.

Shank: The shaft of a tool, such as a screwdriver.

Short circuit: A "short cut" for unlimited electron movement (current flow).

Short-cycle: Term describing a condition in which a motor turns on and off frequently.

Shorted capacitor: One in which the aluminum coils are permitted to touch.

Shorted to ground: See "Grounded."

Shoulder nipple: A short nipple that includes a very short section of unthreaded pipe.

Sight glass: A small window placed in the liquid line on commercial systems to provide a view of the flowing liquid.

Single-phase loads: Devices designed to operate with just two hot wires from a three-phase system.

Single-pole, double-throw (SPDT) switch: Switch that has one pole and operates two contacts (one normally open, the other normally closed).

Single-pole, single-throw (SPST) switch: Common household switch with one pole that closes or opens one contact.

Single-pole breaker: Circuit breaker used to disconnect the black (hot) wire on 120V, single-phase branch circuits.

Single-stage oil pump: Pump used on one-pipe systems, where the oil storage tank is located above the burner assembly.

Slip: The difference between synchronous speed and actual motor speed under full load.

Sludge: A dark, gummy mass caused by a chemical breakdown of oil that combines with other materials, such as carbon, metals, oxides, or salts.

Slugging: A condition in which the compressor must pump liquid, rather than vapor. Liquid slugging can cause severe compressor damage.

Socket: An individual cylinder-shaped box-end tool, used with a handle to perform the same turning tasks as other wrenches.

Soft soldering: See "Soldering."

Solder: An alloy usually consisting of tin and another low-melting point metal, such as lead.

Soldering: The process of joining two pieces of base metal with the use of a filler alloy at a temperature less than 840°F(450°C).

Solenoid valve: An electromagnetic valve that is either fully open or fully closed, depending upon whether electricity is on or off.

Solidus: Melting point of a solder.

Soluble: Easily dissolved.

Solvent cement: Chemical used to soften and join plastic pipe and fittings.

Solvent-welding: Chemical process used to join plastic pipe.

Specific heat: The amount of heat required to raise the temperature of one pound of *any* substance one degree Fahrenheit.

Splash system: A lubrication method in which the crank throw dips into the oil and splashes it around inside the compressor.

Split-phase motor: One that has a start winding is installed in the stator to produce a magnetic field that is "out of phase" with the main winding.

Spray angle: Specific coverage of nozzle that must conform to the combustion chamber and burner requirements.

Spring benders: Springs are designed to be slipped over tubing to completely cover the area of the bend and prevent kinking.

Square measure: A measurement of two dimensions, length and width.

Square units: Means of expressing the surface area of a shape, such as square inches or square centimeters.

Squirrel cage rotor: The most common rotor type used in induction motors. Its body consists of copper bars inserted into slots formed in the surface of the core.

SSV: See "Suction service valve."

Stable: Unchanging or not subject to breaking down.

Stack control: Loss of flame detector found on older oil furnaces. It uses a bimetallic sensing element instead of a cad cell.

Stage: Come on or go off in sequence.

Standard conditions: Uniform standards for evaluating refrigerants. Standard conditions have been established as 5°F (15°C) evaporating temperature and 86°F (30°C) condensing temperature.

Standing pressure test: Method of leak detection that involves pressurizing the system and testing the following day to determine if pressure loss has occurred.

Start capacitor: The capacitor used on some motors to create better starting torque.

Start winding: Additional winding that establishes another magnetic field in the stator that is "out of step" with the main winding.

Starve: Term describing what happens to the evaporator if not enough liquid is metered in.

Static: Term used for condenser that does not involve the use of forced air for heat removal.

Stator: Assembly of stationary electromagnets in a motor.

Stinger leg: A higher-voltage wire from a three-phase delta transformer.

Strap-type pipe wrench: Wrench with strap tightened around the pipe to avoid tooth marks.

Street elbow: Angle fitting that contains a female end and a male end.

Stubs: Short copper-coated steel pipes welded to openings in the housing of a hermetic compressor for attaching tubing or valves.

Subcooled: Term that describes a substance at a temperature that is below its saturation point.

Subcooling: A temperature that is *below* the saturation point.

Suction accumulator: A device used to keep liquid refrigerant from entering the compressor.

Suction accumulator: A receptacle for refrigerant designed to prevent liquid floodback during defrost.

Suction line: Copper tubing that connects the evaporator outlet to the compressor intake in a refrigeration or air conditioning system.

Suction pressure: The boiling point in the evaporator.

Suction service valve: Valve located on the low-pressure side of the system that allows the technician to take pressure readings and to control refrigerant flow to the compressor.

Superheat: A temperature *above* the saturation point.

Superheated vapor: A gas that has been heated to a temperature that is above its boiling point as a liquid at the existing pressure.

Supply air ducts: Ducts carrying air to the conditioned space. Return air ducts: The ducts bringing air back to the furnace for reconditioning.

Surface area: Square measure found multiplying length times width.

Swaging: Enlarging the diameter of an end of one length of copper tubing so that the end of the other length can be slipped into it.

Sweat soldering: Joining method used with either hard-drawn or soft copper tubing that employs capillary action to draw solder into fitting joints.

Swing space: Room needed to turn a nut or bolt.
Switch: Device that stops electron movement to a load by breaking (disconnecting) the circuit.
Synchronous speed: Situation in which the rotor speed matches the rotating magnetic field in the stator poles.

T

Tagout: The practice of placing tags on all operator switches to inform others that repairs are in process.
Tap: A tool used to cut threads inside a hole.
Tapered: Sloped or steadily reduced in diameter.
Taps: On a multi-speed motor, wires or terminals that make it possible to select the number of poles being used.
Tare weight: The weight of the container before being filled.
Tees: Fittings that allow connecting a branch circuit onto an existing line of copper tubing or pipe
Temperature difference (td): The differential that must exist between ambient air and the refrigerant in order to have heat transfer from hot to cold.
Temperature: Measurement that describes the intensity, or heat *level* (how hot or cold), of a substance.
Temperature range: The specific span of temperatures within which controls are designed to operate.
Terminal connectors: Small metal tips that crimp onto the wire ends to make connections simpler and faster.
Terminals: Electrical connection points on such devices as transformers and motors.
Terminate: To begin an action or sequence of events (such as a cooling cycle).
TEV: See "Thermostatic expansion valve."
Thermocouple: A safety device that prevents the main gas valve from opening if there is no pilot flame.
Thermodynamics: The science that deals with the mechanical action of heat.
Thermostat: A temperature-activated switch.
Thermostat override: Continued furnace operation after the thermostat is satisfied.
Thermostatic expansion valve: The most common refrigerant control valve.
Thread angle: The V-angle of the threads. The sides of the threads normally form an angle of 60°.
Threaded rod: Metal rod with its entire length threaded. It can be cut to any length with a hacksaw.
Threads per inch: Measurement determined by counting the number of crests (or roots) per inch of threaded section.
Three-phase loads: Electrical devices designed for connection to all three hot wires.
Three-pole breaker: Circuit breaker used to disconnect all three hot wires on a three-phase circuit.
Throw: Movement of the pole in an electrical switch.
Time-initiated/pressure-terminated timeclock: Timer that terminates the defrost cycle on rising pressure in the suction line.
Time-initiated/time-terminated timeclock: Timer used to place the system into defrost according to time of day, and terminate the defrost cycle after a specified length of time.
Tinning: Term used to describe the spreading action of solder.
Toggle bolt: Threaded fastener with spring-loaded wings. The wings spread out and bear against the inside of the wall. Toggle bolts are used to fasten heavier objects to a hollow wall.
Ton of refrigeration effect: Heat removal rate equal to 288,000 Btu/24 hours, 12,000 Btu/hr., or 200 Btu/min.
Torque: Turning force, usually measured in foot-pounds (ft./lb.) or inch-pounds (in.-lbs.)
Toxicity: Degree of safety or poisonousness of a substance.
Transformers: Electrical devices that make it possible to increase (step up) or decrease (step down) voltage.
Transient light: Stray light that could affect a cad cell (flame safeguard device for oil furnaces).
Troubleshooting: Process of gathering the information needed, then making an intelligent decision about a system problem.
Tubing cutter: Tool used to make an accurate 90° cut on either hard or soft copper tubing.
Two-stage compressors: Compressors that are divided internally into low (or first) and high (or second) stages.
Two-stage heating system: System that tries to match an electric furnace's heating ability to the actual heating requirement.
Two-stage heating thermostat: Control device used with a two-stage electric heating system.
Two-temperature system: A system that has two evaporators, operating at different temperatures, connected to a single compressor.

U

Ultra-low: Temperatures from -50°F to -250°F (-46°C to -157°C).
Undercharge: An insufficient amount of refrigerant.
Undersized: A transformer with a secondary coil that cannot carry the current.
Unified Thread: Now the standard thread. Interchangeable with American National threads.
Union: Fitting that provides a leakproof joint that can be disconnected at the mechanical connection.
Units: In mathematics, a value of *one.* The place value of the digit farthest to the right.
Universal joint: A type of swivel for a socket wrench handle that permits reaching around objects.

Unloaders: Devices that hold the suction valves on one or more cylinders open or closed to reduce compressor capacity.

V

VAC: Abbreviation for "volts, alternating cycle." Units used in rating capacitors.

Vacuum pump: Device used to remove all gas and moisture from a refrigeration system.

Valence electrons: Those orbiting farthest from the nucleus, which are more lightly held and can move from one atom to another. Also called "free electrons."

Value: Number or quantity.

Valve plate: A specially milled steel plate located between the head and the piston cylinders of a compressor. It holds the valve reeds and serves as a division point between the high-side pressure and low-side pressure.

Valve reed: A thin piece of steel located on top of the compressor cylinder and under the valve plate. This thin reed flexes to open and close.

Vanes: The blades mounted on a rotor inside a compressor or other rotating machine.

Vapor charging: Adding refrigerant vapor to the low-pressure side.

Vaporized: Turned into a gas.

Variable: A factor that changes.

Velocity: Speed.

Vertex: The starting point of an angle, from which two lines diverge.

Vertical riser: A vertical portion of the suction line, usually used with an oil trap, in a commercial refrigeration system.

Vertical-down joint: A type of joint where the fitting is below the point where the alloy is applied.

Vertical-up joint: A type of joint where the fitting is above the point where the alloy is applied.

Vibration eliminators: Devices used at the compressor to prevent transmission of noise and vibration to refrigerant piping.

Viscosity: The ability of an oil to maintain good lubrication despite temperature changes.

Voltage relay: Relay that upon the counter-emf (potential) that is generated by the start winding. *Usually called a "potential relay."*

Voltage: The potential difference or electromotive force (emf) that causes electrons to move.

Volts: Measuring unit for the amount of emf.

Volume: The space within a container or space defined by the dimensions of height, length, and width. Always expressed in cubic terms.

Volumetric efficiency: A comparison of the amount of gas *actually* pumped by a compressor to the amount of gas it *should* pump, according to piston displacement and length of stroke.

Volute: The case containing the spinning rotor in a centrifugal compressor or pump.

VOM: A volt-ohm-milliammeter. See "Multimeter."

W

Washers: Disks of metal or other material with a hole through the center. Used to extend the gripping area of a fastener or to prevent a nut from loosening.

Water vapor: Water in a gaseous form.

Water-cooling tower: A structure that captures the water leaving the condenser of a water-cooled refrigeration system and lowers its temperature so that it can be recirculated through the condenser.

Wattmeter: A special meter designed to measure the power (wattage) used by an appliance or home.

Watts: Measuring units for electric power ("work").

Whetstone: A special sharpening stone used with cutting tools.

Width: Linear measure of one dimension (usually across) of an object.

Win-win situation: One in which both parties benefit.

Wire: A single strand or filament of drawn metal.

Wire nuts: Solderless screw-on connectors.

Work-hardening: Process in which copper hardens as a result of vibration, oxidation, and bending.

Working pressure: A test pressure at which fuel gases are used. It is reduced from the far higher cylinder pressure.

Wrought fittings: Fittings, usually made of copper but sometimes of brass, that are sweat-soldered to either hard-drawn or soft copper tubing.

Wye: Type of three-phase transformer with windings similar to a letter "Y."

Z

Zerk fitting: Fitting used to inject grease for lubricating a bearing.

Zero potential: No voltage.

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